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The Human wrist

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THE HUMAN WRIST

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INTRODUCTION

We tend to think of the wrist as a simple joint which allows the hand to move relative to the forearm. In fact, the wrist is one of the most complex structures in the body, made up of numerous articulations between the radius, the eight carpals, the five metacarpals, and the contents of the ulnocarpal space. Despite centuries of study, hundreds of books and articles, and the appearance in 1975 of a journal devoted exclusively to research on the human hand (Journal of Hand Surgery), the wrist remains a poorly understood structure.

Researchers at the University of Rochester School of Medicine and Dentistry/ Strong Memorial Hospital have recently made important advances in our understanding of two aspects of the wrist: the anatomy of the Triangular Fibrocartilage Complex (TFCC) and the movement of the carpal bones during wrist motion. Dr. Richard J. Miller of the Department of Orthopedics and Dr. Sarah Totterman of the Radiology Department have used high resolution Magnetic Resonance Imaging (MRI) to study the detailed anatomy of the poorly-understood Triangular Fibrocartilage Complex, a mass of cartilage and fibrous connective tissue lying between the distal ulna and the proximal carpal row. They have correlated their MRI scans with gross dissection and histological sections of the same wrist specimens. In researching this topic, Drs. Miller and Totterman have found that the existing illustrations of the TFCC in gross dissection are ambiguous and sometimes inaccurate. Nevertheless, these same illustrations have been "recycled" in the literature for years. For the first part of my thesis, I chose to create a series of illustrations of the TFCC showing both the normal anatomy and two of its more common pathologic conditions.

Dr. Miller has also developed a new technique for visualizing the complex movement of the eight carpal bones during wrist motion. In the past, this has proven to be a difficult task since x-rays provide a poor image of the bones, especially when the wrist is flexed or extended. Dissecting the wrist to demonstrate the position of the carpals requires an arthrotomy (opening the joint capsule) which disrupts the wrist ligaments and alters their range of motion. Instead, Dr. Miller removes the skin and forearm tendons from a cadaver wrist and inserts steel wires into the carpal bones perpendicular to the flat surface of the hand. About two inches of each wire is left protruding from the wrist. As the hand is moved relative to the forearm, the carpals move and the wires move with them, tracking the rotational and translational movements of each bone. While this technique has greatly improved our understanding of both qualitative and quantitative carpal motion, these concepts are very difficult to convey with the written word or even with static images. For the second part of my thesis, I sought to develop a computer tutorial, complete with short animated sequences, that could be widely distributed to aid in the understanding of carpal motion. To create this tutorial, it was first necessary to create several illustrations of the wrist which could be digitized and then modified on the computer to create individual frames for the animated sequences.

Both of these topics are quite complex and represent the "state-of-the-art" in our understanding of the wrist. All of the illustrations and the computer tutorial are aimed at the practicing orthopedist, the orthopedics resident, and the advanced medical student. The illustrations were created for publication in a medical journal or textbook and the computer tutorial was designed to be easily distributed to all Macintosh® users in the medical field.

ANATOMY OF THE WRIST

The wrist is a complex anatomic structure which includes the carpo-metacarpal joint (distally), the carpals and all of their articulations, the radiocarpal joint, and all of the structures within the ulnocarpal space. The distal radius may be regarded as part of the wrist since injuries to the distal radius often affect wrist motion. The radioulnar joint, however, is not considered part of the wrist and is functionally part of the forearm (Taleisnik 1985).

The carpal bones themselves are arranged in two rows, one proximal and one distal. The proximal row includes (from medial to lateral) the scaphoid, lunate, triquetrum, and pisiform. Proximally, the scaphoid and lunate articulate with the distal surface of the radius, forming the radiocarpal joint. The distal surface of the radius slopes volarly and toward the ulna and is divided into two concave facets, one medial to receive the scaphoid and one lateral to receive the lunate. The triquetrum and lunate have a proximal articulation with the structures of the ulnocarpal space (called the ulnocarpal complex or triangular fibrocartilage complex). Under normal circumstances, these structures separate the triquetrum and lunate from the ulna. Only when pathology has resulted in the erosion of the triangular fibrocartilage complex can these bones make direct contact. In a healthy individual, the ulna makes no contribution to the wrist.

The distal carpal row includes (from medial to lateral) the trapezium, trapezoid, capitate, and hamate. These bones articulate with the proximal row to form the midcarpal joint. Distally, the distal row bones articulate with the metacarpals to form the carpo-metacarpal joint. Metacarpal I ("thumb") articulates with the trapezium, metacarpal II with the trapezoid, metacarpal III with the capitate, and metacarpals IV and V articulate with the hamate.

Also included in the wrist are the dozens of ligaments which connect the carpals to one another and to the metacarpals and radius. As we shall see, there is not a single ligament that directly connects the ulna to the carpals. Instead, a few ligaments arise from the triangular fibrocartilage complex which itself originates on the radius. The muscles which control the movement of the wrist all originate in the forearm and insert distal to the carpometacarpal joint. There is not a single muscle origin or insertion within the wrist proper. (The pisiform is actually a sesamoid bone that forms within the extensor carpi ulnaris tendon and may, therefore, be considered an exception.)

The ligaments of the wrist can be classified into two broad groups: the extrinsic ligaments which connect any of the carpals to either the radius or the metacarpals; and the intrinsic ligaments which connect the carpals to one another.

The extrinsic ligaments are further subdivided into a proximal group (connecting the radius to the carpals) and a distal group (connecting the carpals to the metacarpals). The proximal extrinsic group includes: a single dorsal radiocarpal ligament connecting the dorsal rim of the radius to the dorsal surfaces of the lunate, triquetrum, and scaphoid; a group of ligaments connecting the volar rim of the radius with the scaphoid, capitate, and lunate (radioscaphocapitate, radioscapholunate, and radiolunate); the radial collateral ligament along the medial edge of the radiocarpal joint; and the ulnocarpal complex or triangular fibrocartilage complex which will be discussed in more detail later.

The intrinsic ligaments are classified according to length; short, intermediate, or long. Each short intrinsic ligament connects a single pair of adjacent carpals and has a dorsal, volar, and interosseous (between the bones) component. The intermediate intrinsic ligaments also connect adjacent carpals (specifically the lunate-triquetrum, scaphoid-lunate, and scaphoid-trapezium) but are somewhat longer. There are only two long intrinsic ligaments, one volar which connects the capitate to the scaphoid, triquetrum and (rarely) the lunate, and one dorsal which originates on the triquetrum and inserts on the scaphoid and trapezium (Taleisnik 1976).

THE TRIANGULAR FIBROCARTILAGE COMPLEX

The space between the carpals and the distal tip of the ulna is filled with a mass of ligaments and cartilage known as the ulnocarpal complex or triangular fibrocartilage complex (TFCC). This complex is essentially a loop of ligamentous tissue which originates on the dorsoulnar corner of the radius, passes medially around the styloid process of the ulna and then gives rise to two branches, the ulnotriquetral and ulnolunate ligaments, which pass volarly to insert on the volar surfaces of the triquetrum and lunate, respectively.

In lower primates, the ulnar styloid is long and articulates directly with the triquetrum. In this case, the portion of the TFCC which wraps around the ulnar styloid becomes cartilaginous and forms a meniscus, much like the cartilage meniscus within the human knee joint. In man, contact between the ulna and triquetrum is lost and the ulnar styloid has receded proximally, leaving a gap between the two bones (Lewis 1967). Nevertheless, the portion of the TFCC that wraps around the ulnar styloid has remained thick and cartilaginous and is generally referred to as the meniscus homologue (because it is evolutionarily homologous with the true meniscus of lower primates). The gap that is left by the receding ulna is filled with a new cartilaginous structure, the triangular fibrocartilage or articular disc. Both the meniscus homologue and articular disc cover the distal surface of the ulna and articulate with the triquetrum, replacing the ulnotriquetral articulation found in lower primates.

As I mentioned above, all of the fibers that contribute to these structures originate on the dorsoulnar corner of the radius. From there the fibers fan out medially (toward the ulna) and volarly, covering the radioulnar joint and the distal surface of the ulnar head. The articular disc forms as a thickening at the center of this fan, directly over the ulnar head. Some of its fibers continue laterally to insert on the ulna at the junction between the styloid process and ulnar head proper. The remaining fibers loop around the ulnar styloid and turn back towards the radius. This part of the complex also thickens to become the meniscus homologue. Some of its fibers insert on the ulnar styloid while others may join the sheath of the extensor carpi ulnaris tendon and extend distally as far as the base of the fifth metacarpal. The bulk of the fibers, however, give rise to the ulnolunate and the ulnotriquetral ligaments (Palmer and Werner 1981). The names of these ligaments are confusing as they imply an origin on the lunate. In fact, they originate on the meniscus homologue which itself originates on the radius. These ligaments might be more properly called the radioulnolunate and radioulnotriquetral ligaments as the fibers originate on the radius, form some insertions on the ulna, and then pass to the carpals in question.

In cross section (coronal or sagittal) the triangular fibrocartilage complex is thinnest in the middle where it overlies the ulnar head and thicker near its edges, including its origin on the radius and its attachment to the ulna. Lying between the thin center of the TFCC and the ulnar head is a synovium-filled space, the prestyloid recess. This space is probably another remnant of the continued regression of the ulnar styloid away from the carpals. It is lined with vascular tissue and may assume pathologic significance in rheumatoid arthritis or other diseases in which synovitis is present (Taleisnik 1985).

The so-called ulnar collateral ligament is another important component of the ulno-carpal complex. Like several of the other structures in this area, its name is misleading; it is not a separate ligament at all. Instead, the ulnar collateral ligament represents a thickening of the dorsal retinaculum where it merges with the sheath of the extensor carpi ulnaris tendon. Neither the retinaculum nor the ECU tendon attach to the ulnar head, but they do receive some fibers form the TFCC. This thickening extends distally to insert on the triquetrum, the hamate, and the base of the fifth metacarpal (Taleisnik 1976).

At this point it should be reiterated that none of the so-called ulnocarpal ligaments actually originate on the ulna, nor is there a single ligament that directly attaches the ulna to the carpals. The ulnolunate and the ulnotriquetral ligaments actually attach the dorsoulnar corner of the radius to the volar carpus by way of the ulnar styloid, and the ulnar collateral ligament is not a separate ligament.

This rather odd arrangement actually has an important function in stabilizing the movements of the wrist. The meniscus homologue, articular disc, and synovium-filled prestyloid recess, all lying between the ulna and the carpals, act as a cushion for the ulnar portion of the wrist. In addition, the arrangement of fibers acts to stabilize the motion of the ulna relative to the radius during pronation and supination. These fibers originate on the dorsoulnar corner of the radius, wrap around the ulnar styloid, then turn back toward the radius to insert on the volar surface of the triquetrum and lunate. These carpals, in turn, are attached to the volar surface of the radius. Thus, the ulna is suspended from the radius by a continuous "sling" of ligaments. As the ulna rotates about the radius during pronation and supination, this sling holds the two bones in close proximity (Palmer and Werner 1981).

This system can be disrupted by damage to any of the ligaments, but the most common pathology by far is perforation of the meniscus homologue and/or articular disc. One study reported perforation of the articular disc in 27.6% of one hundred cadavers examined (Viegas and Ballantyne 1987) while another report found perforations in more than half of the specimens dissected (Palmer 1990). There is a dramatic increase in the incidence of TFCC perforation with age (Mikic 1978) so these numbers may be exaggerated by the advanced age of most cadaver specimens. The incidence of perforations in the population as a whole is probably much lower. Nevertheless, perforation of the TFCC is extremely common and becomes both more likely and more pronounced with age.

Perforation of the TFCC seems to result from close approximation of the ulna and lunate, a problem which is particularly common in people with long ulnar styloids (Palmer and Werner 1981). Perforation results in the opening of the prestyloid recess, direct contact between the ulna and lunate, erosion of their articular cartilages, and inflammation of the prestyloid synovial membrane. The abutment and inflammation cause pain which may be confused with other wrist ailments.

ILLUSTRATING THE TRIANGULAR FIBROCARTILAGE COMPLEX

There are very few illustrations of the TFCC and those that do exist are crude and often confusing (see Taleisnik 1976; 1985). While there exist some decent photographs of these structures, they lack the clarity and simplicity of a good illustration. Therefore, the first part of my thesis involved producing clear, accurate illustrations of the TFCC that were suitable for publication. I chose to create these illustrations using ink since this medium allows for a great deal of detail and holds up well in reproduction. I decided not to use carbon dust (my second choice) primarily because it is more expensive and complicated to reproduce. Since many of the specialized journals in the medical field lack the most sophisticated reproduction resources and often charge the authors for the cost of reproducing illustrations, I felt it best to use pen and ink.

For references, I studied the existing literature on the TFCC, consulted with Drs. Miller and Totterman at Strong Memorial Hospital, and studied their high resolution Magnetic Resonance Imaging (MRI) scans of the wrist. When I felt comfortable with the anatomy of the TFCC region, Dr. Miller and I dissected two fresh cadaver wrists from the hospital's Institutional Donor Program. Later, I dissected two more wrists (the left and the right) from a preserved cadaver specimen in the Gross Anatomy laboratory at the University of Rochester College of Medicine and Dentistry. In every case the TFCC was exposed by removing the skin from an area extending approximately four inches on either side of the wrist, cutting the extensor retinaculum and extensor tendons, and opening the dorsal joint capsule. Once the TFCC was exposed, I made several sketches of the area from several different views.

The finished pieces were drawn using Rotring® rapidograph pens on Bienfang® Satin Design 150H transparent natural vellum. To scratch out ink lines, I used a #10 X-Acto® blade. This technique is particularly useful when breaking the outline of an object which passes behind another object, creating more of an illusion of overlapping.

One set of line drawings (Fig. 1) shows the normal anatomy of the TFCC and an orientation drawing with the wrist incision indicated. The wrist is shown dissected open and is accompanied by a blow-up of the TFCC area. Figure 2 shows a perforation of the TFCC which I observed in the left wrist of the preserved cadaver in the Gross Anatomy Laboratory. The ulnar head can be seen through the perforation. Interestingly, this same cadaver showed a different pathologic condition in the other wrist. Figure 3 shows an unusual U-shaped tear of the TFCC, separating the articular disc from the meniscus homologue. The articular disc, attached to the rest of the TFCC only at its dorso-radial corner, can be lifted dorsally to expose the ulnar head below.

Backlit stats of the finished drawings were shot in the NTID Printing Production Laboratory and these were then cut out and placed into new layouts. These images were then copied at 75% of their original size for display in this thesis report.

In addition, stats were taken at 50% of their original size and I pasted all of the images into a single 8 x 10" layout. This was scanned into a Macintosh® computer using a black-and-white Apple Scanner and Apple Scan™ software. I then imported this image into Letraset's Design Studio™ page layout software to create labels and an imaginary textbook page design. I did this merely to simulate what the illustrations would look like in print.

By checking the "Don't Print" button on the picture dialog box, I was able to print out only the text and labels and not the scanned image. I then copied the text layout onto a piece of xerographic acetate to create a text overlay for this imaginary layout. Figure 4 shows the reduced images with the overlaid text, all of which was statted again at 75% to fit the dimensions of this thesis. Refer to this figure for a key to the structures seen in Figures 1 3.

KINEMATICS OF THE WRIST

Kinematics is the study of motion. Taken as a whole, the wrist is capable of just six motions flexion, extension, radial deviation, ulnar deviation, pronation, and supination. However, during these movements, each of the eight carpal bones has its own unique range of motion. To fully describe the kinematics of the wrist, it is necessary to describe the motion of each carpal relative to the radius and to one another.

The movement of one object relative to another such as occurs at a joint can be described by six different parameters or "degrees of freedom." These parameters consist of three for angular movements (antero-posterior angular projection, lateral angular projection, and rotation) and three for translational displacements (antero-posterior displacement, lateral displacement, and proximo-distal displacement or distraction-override). Most joints are constrained against certain types of motion and therefore can be described as having fewer degrees of freedom. The proximal interphalangeal joint of the finger, for example, is constrained to a single type of motion antero-posterior angular displacement and therefore has a single degree of freedom. The carpals, however, are not constrained in such a way and have a more complex range of motion. Since there are eight carpal bones, there is a total of forty-eight degrees of freedom (six degrees per bone times eight bones) that must be considered during each movement of the wrist.

Fortunately, there are several anatomic features of the wrist which serve to simplify the movements of the carpals. First of all, the intrinsic interosseous ligaments of the distal carpal row bind these bones so tightly that they function as a single, solid unit. The distal row is also tightly bound to the index and long finger metacarpals such that these bones all move in unison. These two metacarpals along with the trapezium, trapezoid, capitate, and hamate form a "fixed unit" which can be considered as a single segment during movements of the wrist.

The scaphoid, lunate, and triquetrum of the proximal row are also linked by interosseous ligaments, though not as tightly as are the bones of the "fixed unit". These bones tend to move in unison, but a small amount of relative motion is permitted. The fourth bone of the proximal row the pisiform is actually a sesamid within the flexor carpi ulnaris tendon and is probably of little significance in the kinematics of the wrist.

From a functional point of view the wrist comprises a solid distal element (fixed unit), a proximal articulating surface (radius) and a fairly rigid segment intercalated in between (the proximal row). As the muscles which control the wrist contract, they tend to draw the metacarpals (and the carpus as a whole) toward the forearm, compressing the carpal bones in between. The distal row, strongly secured to the metacarpals, moves in unison with the carpus as a whole. The proximal row, on the other hand, is squeezed between the distal row and the articular surface of the radius and moves in response. Since the articular surface of the radius slopes volarly, the proximal row tends to slide in a volar direction and rotates into an extended position. This is precisely what happens during extension and ulnar deviation. During flexion and radial deviation, however, the tendency of the proximal row to extend is counteracted by other forces. As the carpus is drawn radially and/or volarly, the distal row impinges on the distal pole of the scaphoid which acts like a lever arm, causing the scaphoid to rotate into a flexed position. Because of its strong interosseous connections with the rest of the proximal row, flexion of the scaphoid causes flexion of the lunate and triquetrum as well, despite their inherent tendency to extend.

One feature of the wrist which greatly simplifies its motion is the fact that all rotational and translational movements are centered about a single point within the head of the capitate (Youm, et. al. 1978). The fixed unit, of which the capitate is a part, pivots and rotates about this point during flexion, extension, ulnar and radial deviation. The proximal row , in turn, is translated along the circumference of a circle which is centered at this same point within the capitate.

It should be noted that because of the double-row structure of the wrist, flexion and extension are actually compound motions, part occurring at the radiocarpal joint and part at the midcarpal joint. As was mentioned previously, the proximal row slides volarly and extends during extension. During flexion, the proximal row flexes relative to the radius. These motions represent the radiocarpal portion of flexion and extension. In addition, there is angular displacement between the proximal row and fixed unit (i.e. at the mid-carpal joint). Interestingly, the capitate head still acts as the center of rotation for both the radiocarpal and midcarpal components of motion; the proximal row slides along the articular surface of the radius following an arc centered in the capitate while the rotation of the fixed unit relative to the proximal row is also centered in the capitate (Youm, et. al. 1978).

The radiocarpal and midcarpal components of flexion and extension each account for about half of the total range of motion of the wrist. However, a small amount of relative motion is allowed between the three bones of the proximal row and, therefore, each makes a slightly different contribution to the radiocarpal component of motion. The movement of the three proximal row bones is extremely difficult to observe and it was for this reason that a special experimental procedure was developed to "externalize" their motion without disrupting the joint capsule. Dr. Richard Miller of the University of Rochester/Strong Memorial Hospital has developed a technique whereby the subtle angular changes of the proximal row bones may be visualized without disrupting the structures of the wrist. This method involves dissecting away the skin and subcutaneous tissue of a fresh cadaver specimen amputated at the elbow. The digits are removed as are the tendons of the first, third, fourth, and fifth compartments, but the flexor and extensor tendons may be left intact to act as "motors" for manipulating the hand. Thin steel Kirschner wires are then inserted through the dorsal joint capsule into each of the proximal row bones and additional wires are placed in the radius (to act as a reference frame) and in the third (long finger) metacarpal (to track the motion of the fixed unit). The wrist is then moved by pulling on the remaining flexor or extensor tendons or by manipulating the third metacarpal (fixed unit). The proximal carpals move passively in response to impingement by the fixed row and this motion is reflected in movements of the protruding Kirschner wires (Miller, unpublished manuscript).

While this method has revealed many of the subtleties of wrist motion, one of its most important contributions is demonstrating the relative motion of the proximal carpals during flexion and extension. This method has shown that, in both of these motions, the scaphoid always pivots the most, the triquetrum somewhat less, and the lunate the least (Miller, personal communication). During flexion, the scaphoid flexes more than the other bones and during extension it extends more than the others. Since the three proximal row bones all move to a different degree relative to the radius, the extent of radiocarpal rotation differs for each. The proportion of total motion that is contributed by the radiocarpal joint differs for each of the proximal row bones. For example, during flexion the wrist traverses an angle of 90 degrees. The scaphoid flexes approximately 60 degrees or about two-thirds of the full range of flexion, the other third (30 degrees) being accounted for by flexion at the scapho-capitate (midcarpal) joint. The lunate, on the other hand, flexes about 40 degrees, accounting for less than one-half of the total flexion of the wrist. The luno-capitate joint flexes the remaining 50 degrees, significantly more than does the scapho-capitate joint. The triquetrum flexes to an extent intermediate between the lunate and scaphoid, or about 45 degrees. The midcarpal joint at the level of the triquetrum flexes about 45 degrees. Although extension of the wrist traverses a smaller angle (approximately 70 degrees), the proportion of movement between the radius and each of the carpals and between each carpal and the fixed unit is the same. For example, extension of the scaphoid accounts for about two-thirds of the total range of motion whereas the lunate accounts for less than one-half or about 30 degrees (Miller, personal communication).

Now that we have established the general principles of wrist motion, we can summarize all of this information by considering each of the basic wrist motions separately. In extension, the carpus rotates 70 degrees dorsally about an axis which lies in the coronal plane and is perpendicular to the long axis of the forearm. The axis of rotation of the carpus is a point centered in the head of the capitate. The fixed unit pivots about this point while the proximal row, pressed against the articular surface of the radius, slides volarly into an extended position, following an arc which is also centered in the capitate. The scaphoid extends about 47 degrees, the triquetrum extends about 35 degrees, and the lunate about 30 degrees. The fixed unit extends relative to the proximal row bones forming angles of 23 , 35, and 40 degrees with the scaphoid, triquetrum, and lunate respectively.

In flexion, the carpus rotates about the same axis but moves volarly through an angle of about 90 degrees. As the carpus is drawn into this position, it impinges on the distal pole of the scaphoid, forcing the proximal row into flexion. The scaphoid flexes approximately 60 degrees, the triquetrum flexes 45 degrees, and the lunate flexes 40 degrees. The fixed unit forms an angle of 30, 45, and

50 degrees with the scaphoid, triquetrum, and lunate, respectively. Because of the ulnar-facing slope of the articular surface of the radius, flexion is always accompanied by a significant degree of ulnar deviation.

In radial and ulnar deviation, the carpus rotates about an axis that lies in the sagittal plane, lies perpendicular to the long axis of the forearm, and passes through the head of the capitate. In ulnar deviation, the carpus rotates medially about 40 degrees. The proximal row, pressed against the sloping surface of the radius, is forced into extension. As with other movements of the wrist, the scaphoid extends the most, then the triquetrum, and the lunate extends the least. In radial deviation, the carpus is deflected laterally, toward the radius, by about 10 degrees. As in flexion, this causes the fixed unit to impinge on the distal pole of the scaphoid and the proximal row bones flex.

WRIST KINEMATICS:
AN INTERACTIVE TUTORIAL FOR THE MACINTOSH®

One of the greatest difficulties in understanding the kinematics of the wrist is visualizing the coordinated movement of all of the carpals in several different planes. While a series of static illustrations may be helpful in achieving this goal, an animated sequence is much more dramatic and effective. For the major part of my thesis , I chose to create an animated tutorial program that can be viewed on a Macintosh® computer.

In working with several physicians at local hospitals, I have noticed that the Macintosh® is the computer of choice in the medical field. However, most offices are equipped with smaller Macs, such as the Classic™, Plus™, SE™, or SE30™, which cannot read high-density floppy disks and are limited to 2 megabytes of RAM (Random Access Memory). Furthermore, few of these systems include any sophisticated hardware (such as a Syquest® removable hard drive) or software. I decided then to keep the tutorial as simple as possible using the following guidelines. 1) the tutorial should be created using a program that is inexpensive, readily available, and requires little memory; 2) the tutorial itself should require little memory and should fit onto one or two low-density (800k) floppy disks; 3) it should be in black-and-white at a resolution of 72 dpi (dots per inch) so that it displays properly on the small, built-in monitors of the smaller Macintosh® computers.

Using these criteria, I immediately ruled out two program which are popular choices for the production of computer tutorials: Macromind® Director™ and Aldus® Supercard™. Macromind® Director™ is a sophisticated, full-color animation program that requires a Mac II system or better, a 13 inch , color monitor, and 4 megabytes of RAM. A typical tutorial produced with Director™ can occupy several megabytes of memory and requires a data cartridge or portable hard drive just to transport a copy of the program. Finally, Macromind® Director™ itself has a retail price of about $700 and is not "standard equipment" on most Macintosh® systems.

Another alternative, Aldus® Supercard™, has much more modest requirements than Macromind® Director™, but it is a full-color program that simply reproduced many of the features found in other, less expensive programs. The most suitable choice for my thesis was Hypercard™, a program developed by Apple and currently licensed to Claris. Apple's latest version of Hypercard™ (v. 2.1) requires approximately 700 kilobytes (700k) of RAM, can run on <u>any</u> Macintosh® computer with operating system 6.0.3 or higher, and is limited to 72 dpi black-and-white images. Most importantly, Hypercard™ is distributed at no additional charge with the purchase of every new Macintosh® computer. It is standard equipment on virtually every Mac currently in service.

The tutorial programs produced by Hypercard™ are called "stacks." A stack is a group of computerized "cards," which display on the screen one at a time. The author of the stack can include a variety of objects on a card text, black-and-white bitmapped graphics, and "buttons." A button is a graphic object combined with a short program or "script." When the user clicks on a button with the computer's mouse, the script is executed. A script may be as simple as a command which tells Hypercard™ to proceed to the next card in the stack, or it may initiate a more complex set of tasks such as animation, making sounds, or opening a new stack. An animated sequence is produced by creating a set of cards that are all slightly different, and then writing a short script that tells Hypercard™ to quickly flip through these cards. The user may simply click on a button, executing the script, and objects on screen will appear to move as the image changes from one card to another.

The first step in producing this tutorial was to create the basic card layout. I chose the standard 6 x 9 " format since this completely fills the small screen of low-end Macs and shows up well on larger screens as well. I find that white text on a black background is clearer and easier on the eyes than black-on-white (especially on a computer screen), so I defined a solid black background for all of the cards.

Next, I created the buttons that allow the user to navigate through the stack of cards. I cut and pasted graphic elements from Claris' copyright-free Hypercard™ clip-art, defined each object as a button, and wrote a one line script for each. (Note: a complete printout of the Wrist Kinematics stack is included for reference at the end of this thesis.) The broken arrow button allows the user to start over (return to the first card) from any card in the stack. The stack of cards with a question mark allow the user to return to the table of contents at any time, and the right- and left- arrows allow the user to flip forward or backward through the stack, one card at a time.

The next, and perhaps most important, step in creating this tutorial was producing the artwork that appears on the cards. Initially, I hoped to use half tone illustrations throughout the stack, converting them to bitmapped images in Adobe® Photoshop™ (v. 1.0.7) prior to placing them in the stack. First, I created three carbon dust illustrations of the bones of the wrist: a volar view, a dorsal view, and a superior view looking down the long axis of the forearm (Figures 5, 6, and 7). I scanned these images into a Macintosh® IIci using a LaCie® Silverscanner and the Silverscan™ plug-in software for Adobe® Photoshop™. In Photoshop™, I cleaned up the images, increased their contrast, and converted them to 72 dpi black-and-white bitmaps. Unfortunately, the results were not as good as I had hoped. Because of the low resolution, the individual bones of the wrist were no longer distinct and their subtle surface features were obscured.

Since it is so important to distinguish the individual carpal bones in this tutorial, I decided to use line rather than halftone illustrations throughout the stack. However, the scanned carbon dust images did not go to waste. In Photoshop™, I inverted the images such that they appeared as white on black instead of black/gray on a white background, and I saved them as high-resolution greyscale PICT files. Hypercard™ has a built-in feature that allows a card to display a PICT file in a specially-defined picture window, even though the card itself can only contain low-resolution, bitmapped images. This requires writing a short script for the card:

```
on openCard
      Picture "dorsal.pictA", Pict, rect, false
      show window "dorsal.pictA" at 272,30
end openCard

on close Card
      close window "dorsal.pictA"
end closeCard
```

The Picture command defines the PICT file window, the filename "dorsal.pictA" is the name I used for the PICT file showing the dorsal view of the wrist bones, and the show command displays the window at the specified x,y coordinates. The close command closes the window when the card is closed. Without this command, the window would remain open throughout the rest of the tutorial. I placed PICT windows on several cards at the beginning of the stack because I felt they added some dramatic emphasis to the otherwise drab display. I considered using PICT windows for all of the illustrations in the stack, but found this untenable for two reasons: the PICT files take up a great deal more memory than do the bitmapped images on the cards themselves; and it takes time for the PICT file to load when it is summoned by the show window command. On less Powerful Macs, this can take ten to twenty seconds. Obviously this would not make for a very effective animated sequence.

To create the line illustrations which make up the bulk of the stack, I saved a bitmapped copy of each scanned image and then brought each one into Adobe® Illustrator™ (V.3.0) as a template. Using the pen tool, I traced the outline and surface features of each bone. I saved each line illustration (Figures 9,10, and 11) as an Illustrator™ EPS (Encapsulated Postscript) file with a Black and White Macintosh® Preview so that it can be opened in Photoshop™. I also created a line illustration showing a para-sagittal section of the wrist (i.e., a "side view" showing the radius , proximal carpal row, capitate, and third metacarpal) using a scanned x-ray as a template (Figure 12).

The EPS illustrations cannot be pasted directly into Hypercard™, so I first had to open each line drawing in Photoshop™, convert it to a bitmap, invert it (white-on-black instead of black-on-white), and then copy and paste it into the appropriate card in the Hypercard™ stack. Once the image is pasted into Hypercard™ and properly positioned on the correct card, it is possible to make simple modifications to it using the drawing tools that come with Hypercard™. Most of the arrows and all of the dot-pattern fills in this stack were created in Hypercard™ itself.

Producing the illustrations in Adobe® Illustrator™ greatly simplified the process of creating animated sequences. As an example, I will describe in detail how I created one animated sequence showing ulnar deviation as seen from the dorsal surface of the hand. First, I opened "dorsal.line," the Adobe® Illustrator™ line drawing of the wrist bones in dorsal view. With the direct select tool, I selected all of the carpal and metacarpal bones but not the ulna or radius. I then chose the rotate tool and, with the option key depressed, clicked at a point within the head of the capitate corresponding the center of rotation of the carpus. Doing so defined that point as the center of rotation for the selected objects and holding the option key while clicking opened the rotate tool dialog box. I specified an angle of 10 degrees and clicked "OK." This caused the entire carpus (carpals and metacarpals) to rotate 10 degrees clockwise (toward the ulna in this view), centered around a point within the capitate. I saved this image under a new name and repeated the process three more times, each time causing the carpus to rotate an additional 10 degrees toward the ulna.

In addition to rotation of the carpus, ulnar deviation involves extension of the proximal carpal row. In the dorsal view of the wrist, the distal surfaces of the proximal row will turn toward the viewer while the proximal surface will rotate away from the viewer. To simulate this process, it was necessary to modify the appearance of the proximal carpal bones in each successive frame. To do this, I compressed the bones to simulate foreshortening and I moved the lines representing surface contours of the bones. The final line illustrations are shown in figure 13.

In the end, I had five different dorsal views of the wrist, one in the neutral position and four with the carpus rotated 10, 20, 30, and 40 degrees toward the ulna. I opened each of these illustrations in Photoshop™, converted them to bitmaps, inverted them, and then pasted them into five successive cards in the Wrist Kinematics stack. To link these cards into an animated sequence, I created an invisible button that covered the entire wrist image on the first card of the sequence. I opened the button dialog box and wrote the following script for the button:

```
on mouse Up
        forward
end mouse Up
```

When the user clicks anywhere on the wrist (i.e.. on the invisible button), Hypercard™ executes the command "forward." This is not a command which Hypercard™ normally understands so I had to define it. On the same card, I opened the card dialog box and clicked on the "script" button. In the script dialog box, I entered the following script:

```
on forward
        repeat 4
                go next card
                wait 30
        end repeat
end forward
```

When the forward command is received, this script tells Hypercard™ to close the current card, open the next card and wait 30 ticks (1 tick = 1/60 sec; 30 ticks = 1/2 second). Hypercard™ will repeat this process four times, stopping on the fifth card in the sequence.

The wait 30 command causes a short delay before the next card is opened, giving the user a chance to see the changes that occur with each 10 degree increment. Without such a delay, the cards change so rapidly that it is hard to follow. Initially, I tried to create a delay between frames by simply duplicating several copies of each card and having the animation cycle through a larger number of cards. While this produced the desired effect, the duplicate cards occupied a significant amount of memory, especially since there are fourteen animated sequences in this stack. The wait 30 delay method is much more economical in terms of memory allocation.

On the final card of each animated sequence, I offer the user the option to reverse the movement and return the wrist to the neutral position. This is done by creating another invisible button with the following button script:

```
on mouse Up
	backward
end mouse Up
```

and the following card script:

```
on backward
	repeat 4
		go previous card
		wait 30
	end repeat
end backward
```

Upon returning to the first card in the sequence, the user has the option to view the animation again or proceed to the next topic by clicking the forward arrow. Clicking the forward arrow does not allow the user to flip through the individual frames of the animated sequence.

Not every illustration in this stack is part of an animation. Of the seventy-nine illustrations in the Wrist Kinematics stack, fifty-two are involved in fourteen animated sequences. To distinguish these illustrations from static images, and to initiate the animation, I placed a white box with black lettering on the first and last cards of each sequence. The remainder of the lettering in the stack is white on the black background. To create this white lettering, I first typed black lettering on a white background. Then I used the marquee selection tool to drag a box around the lettering and chose the Invert command from the Paint menu. I used the New York Bold font for all of the lettering; 18 point size for major headings, 14 point for subheadings, and 10 point for most of the text.

So far, I have discussed the techniques I used for creating the cards, text, illustrations, and animations in the Wrist Kinematics stack. However, I have not discussed the actual sequence of cards in the stack, the topics covered, and the order in which the user will most likely flip through the stack. In concluding this section, I will briefly "walk through" the stack, imitating the user flipping through the stack one card at a time. Please refer to the printout of the stack at the end of this thesis.

The first card is essentially a cover page with a PICT window showing the dorsal surface of the wrist bones. Some of the navigation buttons, including "start over", "forward", and "backward", are introduced on this card. The second card is the table of contents. The user can click on any of the topics in the list and Hypercard™ will automatically turn to that section of the stack. This card has a PICT window showing a volar view of the wrist and also introduces the "contents" button which allows the user to return to the table of contents from any card in the stack.

The third card begins a section which briefly reviews the osseous anatomy of the wrist. It includes a PICT window of the volar surface of the wrist, as well as line illustrations with certain bones stippled to identify the proximal and distal rows. The final card in this section shows the superior view of the wrist in both PICT and line formats.

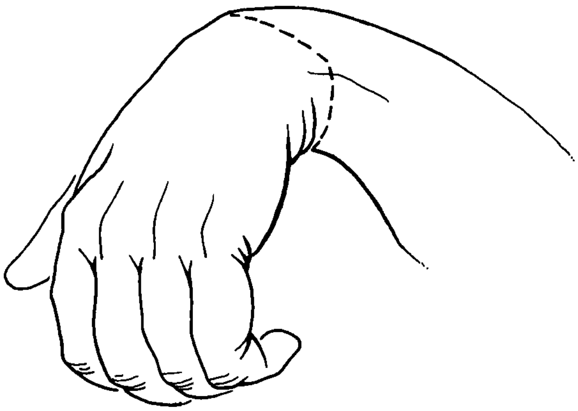
The next section deals with the terminology of wrist movements: flexion, extension, radial deviation, ulnar deviation, supination, and pronation. Three animated sequences, comprising the next eleven cards demonstrate these movements using line illustrations created in Adobe® Illustrator™ from a pencil-drawing template.

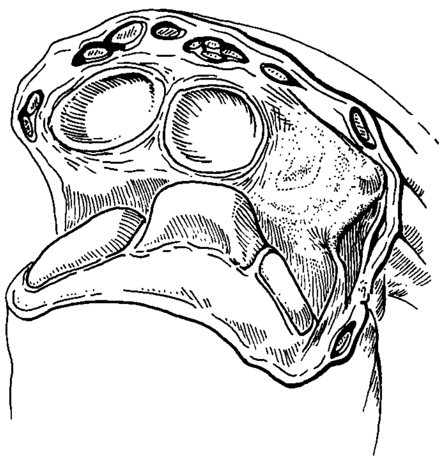
The third section illustrates carpal motion during wrist movements. It starts with a discussion of the concept of degrees of freedom and the potential complexities of carpal kinematics. Six cards then detail the anatomic constraints which serve to simplify our understanding of carpal motion, including the linking of bones into a fixed unit and proximal row. This section continues by discussing some of the general principles of wrist motion, including the location of a rotational center within the capitate, indicated on the illustrations by the intersection of perpendicular axes. The rotation of the carpus about this point is demonstrated with two animated sequences showing lateral (ulnar) deviation and flexion. Also discussed in this section is the flexion or extension of the proximal row during movements of the wrist. Three animated sequences illustrate this phenomenon and also show how the three proximal row bones flex and extend to different degrees.

The Wrist Kinematics tutorial concludes with a summary of each of the principle wrist motions and one or two animated sequences illustrating each. To demonstrate flexion and extension, the wrist is shown in parasagittal cross-section. To demonstrate radial and ulnar deviation, the wrist is shown first from the volar surface and then from the dorsal surface. In every case, the viewer may choose to reverse the animation or move on to the next topic.

The final card in the stack is a short list of references that also includes instructions for quitting the program.

Figure 1. Cadaver wrist (left) dissected at the level of the radiocarpal joint to show the anatomy of the Triangular Fibrocartilage Complex (blow-up). Refer to figure 4 for a key to the structures of the TFCC. (Pen and ink).





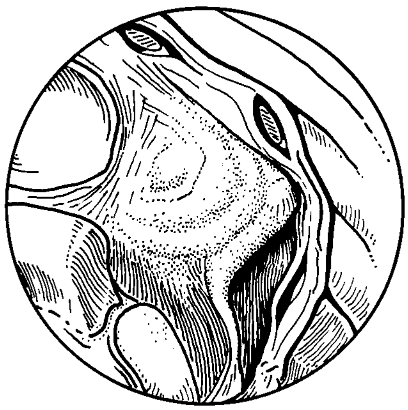


Figure 2. Cadaver wrist (left) showing perforation of the Triangular Fibrocartilage Complex, exposing the head of the ulna beneath. (Pen and ink).

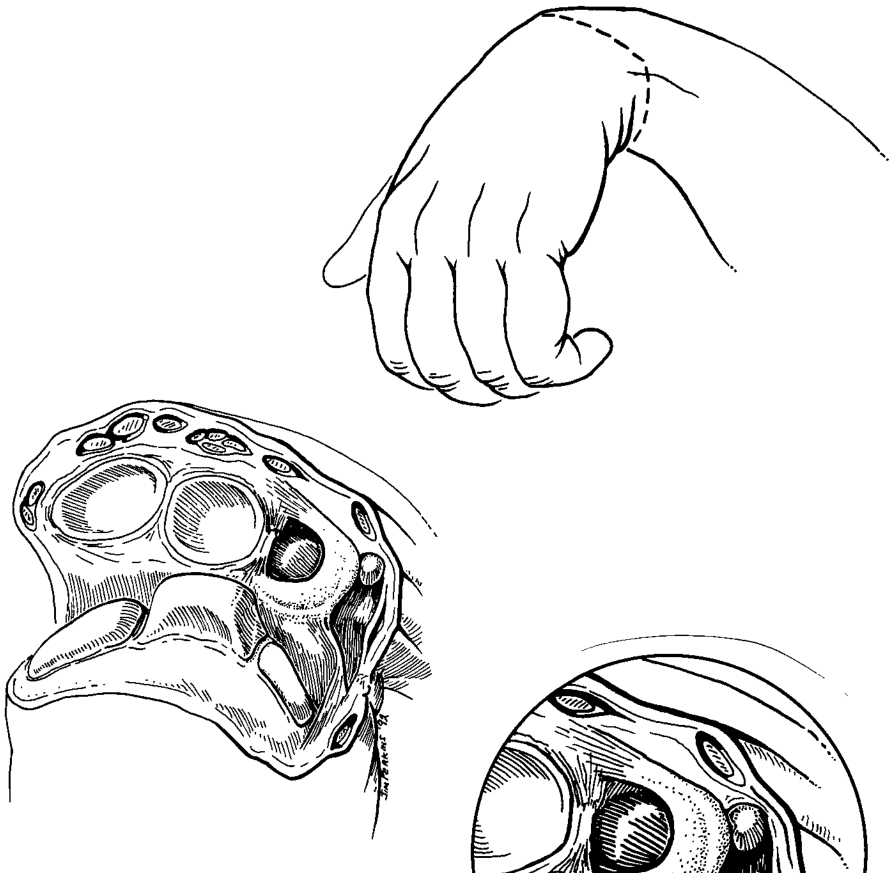


Figure 3. Right wrist of the same cadaver as in figure 2, showing an unusual tear of the TFCC. The articular disk has almost completely separated from the meniscus homologue and can be lifted to expose the ulna. (Pen and ink).

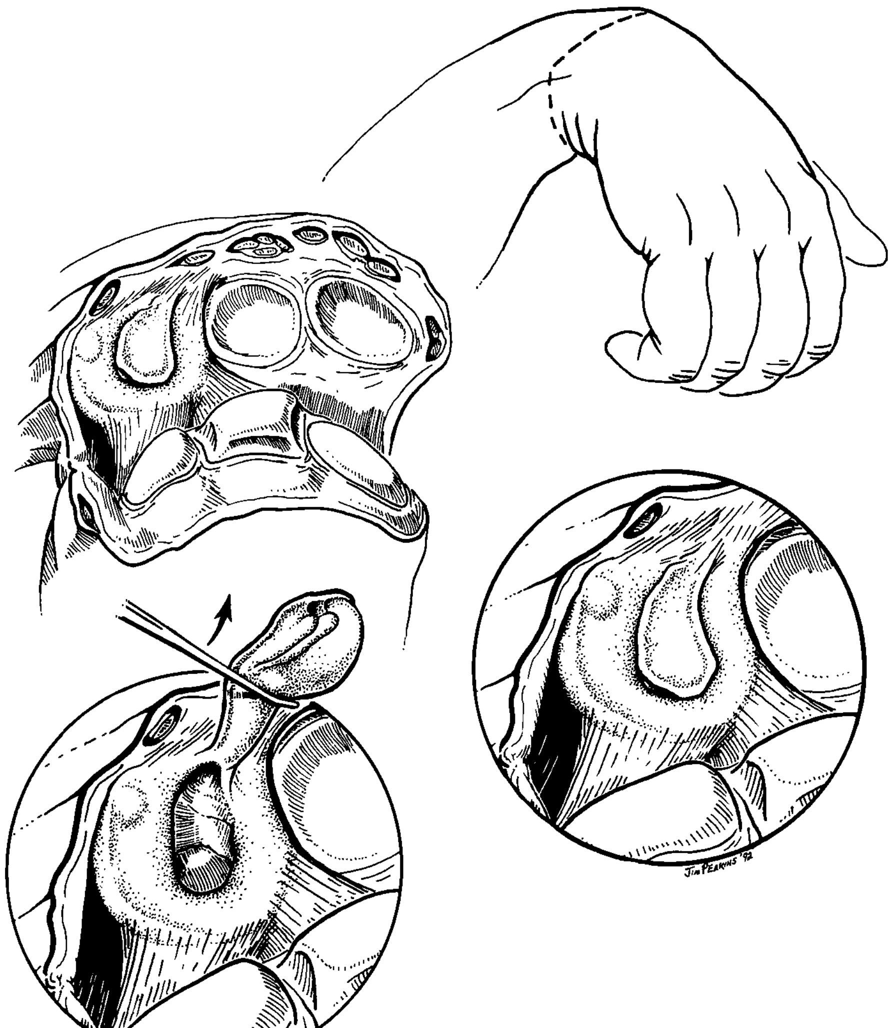


Figure 4. Possible textbook layout of TFCC illustrations. Text and layout created in Letraset Design Studio™.

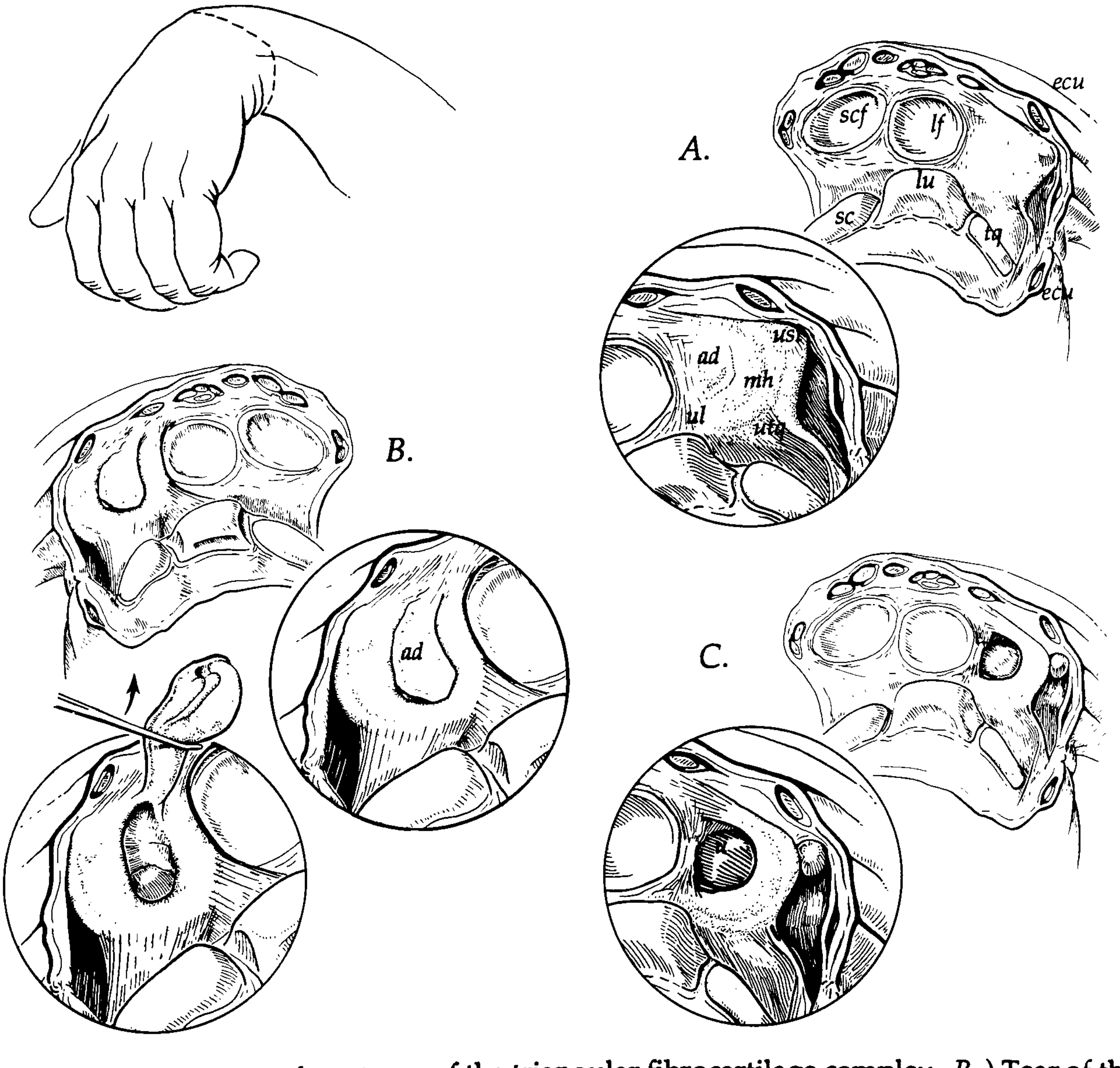


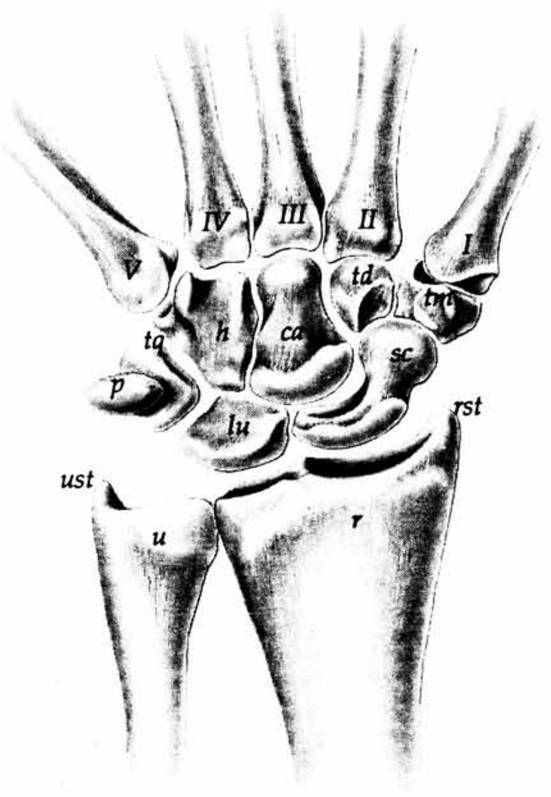
Figure 17. *A.*) Normal anatomy of the triangular fibrocartilage complex. *B.*) Tear of the TFCC leaving a loose flap which has calcified. *C.*) Perforation of the TFCC exposing the ulnar head proximally. *B* and *C* are the right and left wrists of the same cadaver. Abbreviations: *ad*, articular disc; *mh*, meniscus homologue; *ul*, ulnolunate ligament; *utq*, ulnotriquetral ligament; *ecu*, extensor carpi ulnaris tendon; *u*, ulna; *ust*, ulnar styloid; *scf*, scaphoid facet of radius; *lf*, lunate facet of radius.

Figure 5. Volar view of the bones of the wrist. For a key to the bones, see figure 8. (Carbon dust).

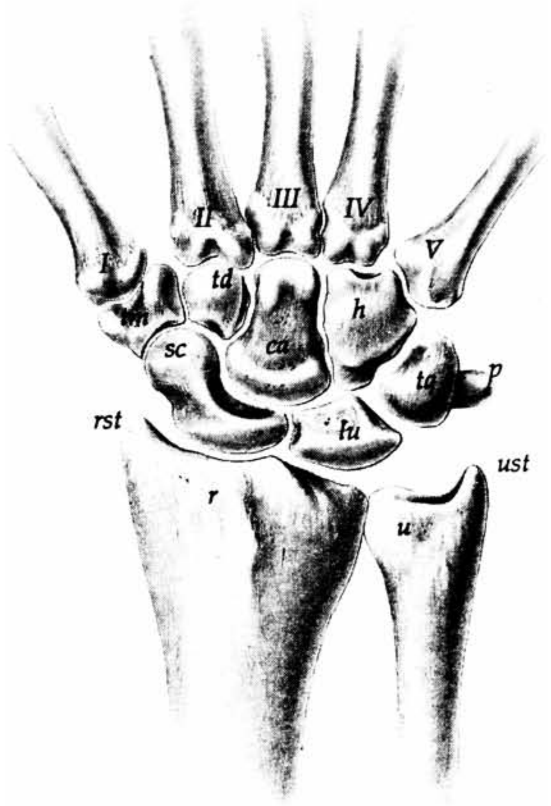
Figure 6. Dorsal view of the bones of the wrist. (Carbon dust).

Figure 7. Superior view of the carpal bones looking down the long axis of the forearm. The concave volar surface is the carpal tunnel. (Carbon dust).

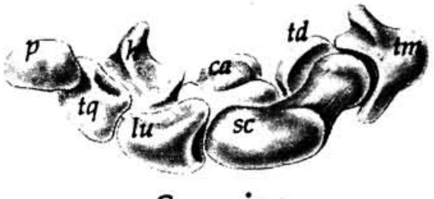
Figure 8. Possible textbook layout of wrist bone illustrations. Text and layout created in Letraset Design Studio™.



Volar



Dorsal



Superior

Figure 1. Volar, dorsal, and superior views of the carpal bones. Abbreviations: *ca,* capitate; *h,* hamate; *lu,* lunate; *p,* pisiform; *r,* radius; *sc,* scaphoid; *td,* trapezoid; *tm,* trapezium; *tq,,* triquetrum; *u,* ulna; *ust,* ulnar styloid; *rst,* radial styloid; *I-V,* metacarpals 1-5.

Figure 9. Adobe® Illustrator™ line illustration of the volar view of the wrist. To create this illustration I used a scanned version of the volar carbon dust (figure 5) as a template.

Figure 10. Adobe® Illustrator™ line illustration of the dorsal view of the wrist. I used the dorsal view carbon dust (figure 6) as a template.

Figure 11. Adobe® Illustrator™ line illustration of the carpal bones in superior view. The carbon dust illustration of the carpal (figure 7) was used as a template.

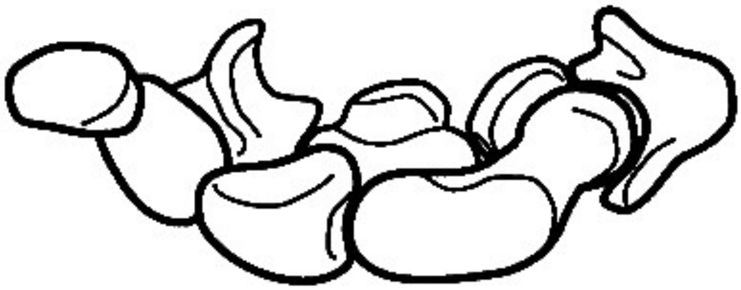


Figure 12. Adobe® Illustrator™ line illustration showing a parasagittal cross section of the wrist.

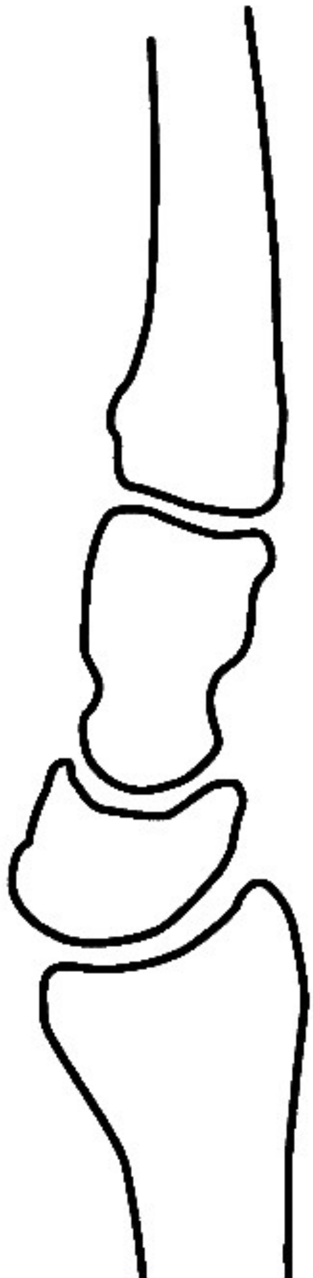
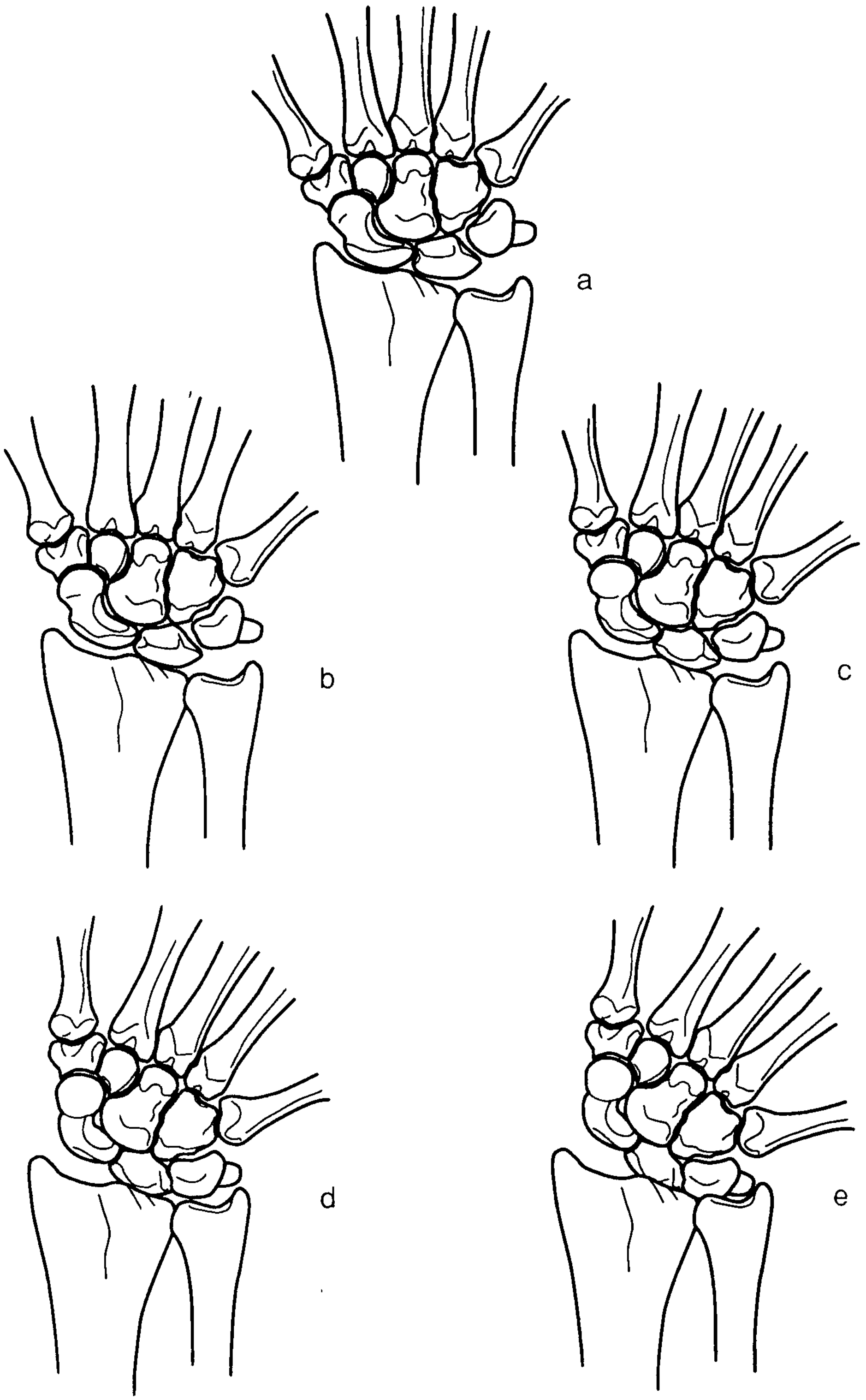


Figure 13. Five line illustrations, all created in Adobe® Illustrator™, which were used to create an animated sequence showing ulnar deviation. a.) Dorsal view of the wrist in the neutral position. b.) Same wrist with 10 degrees of ulnar deviation of the carpus. c.) 20 degrees of ulnar deviation. d.) 30 degrees of ulnar deviation. e.) The wrist in complete ulnar deviation (40 degrees).


a
b
c
d
e

Figures 14 100. A complete printout of the Wrist Kinematics Hypercard™ stack (86 cards). A white box with black lettering indicates the beginning of an animated sequence. The next several cards following one of these white boxes are the individual frames of the animated sequence. The final card in any animation is generally indicated by another white box asking the user to "click on the wrist to reverse the sequence or use the arrow to proceed."

Wrist Kinematics

An introduction to wrist and carpal movements

by Jim Perkins, MS, MFA

Click here at any time to start over

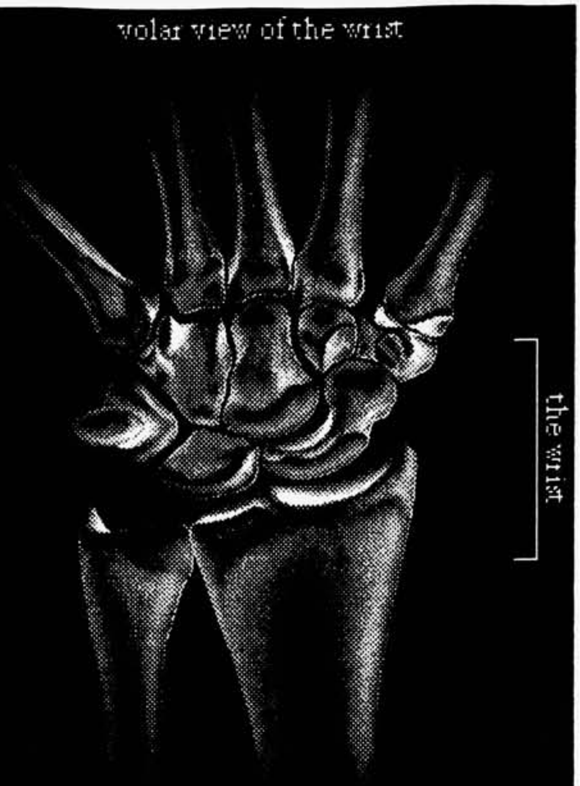
Use these arrows to move forward and back

Wrist Kinematics

(click on a topic or use the arrow keys to page through this tutorial)

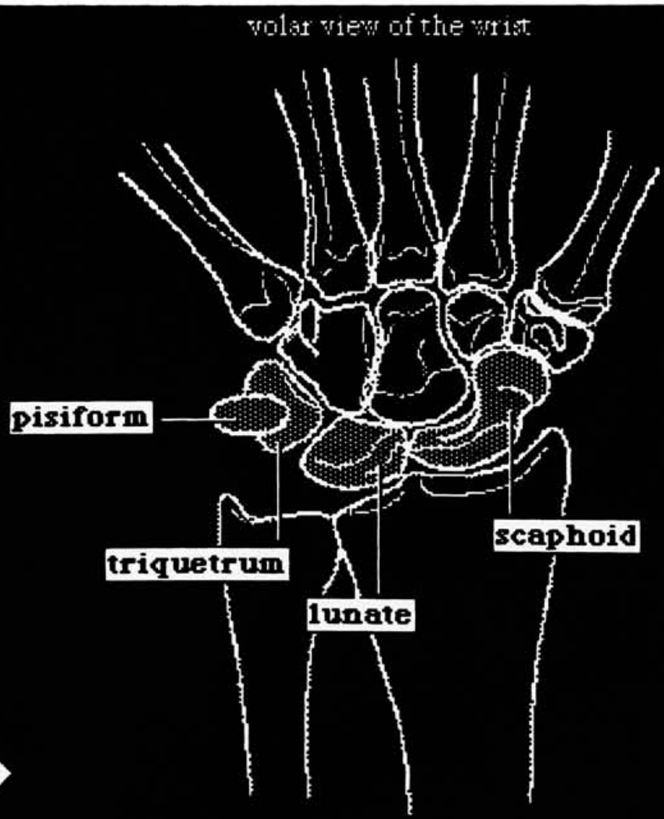
Click here to return to table of contents

The Wrist: A Basic Review



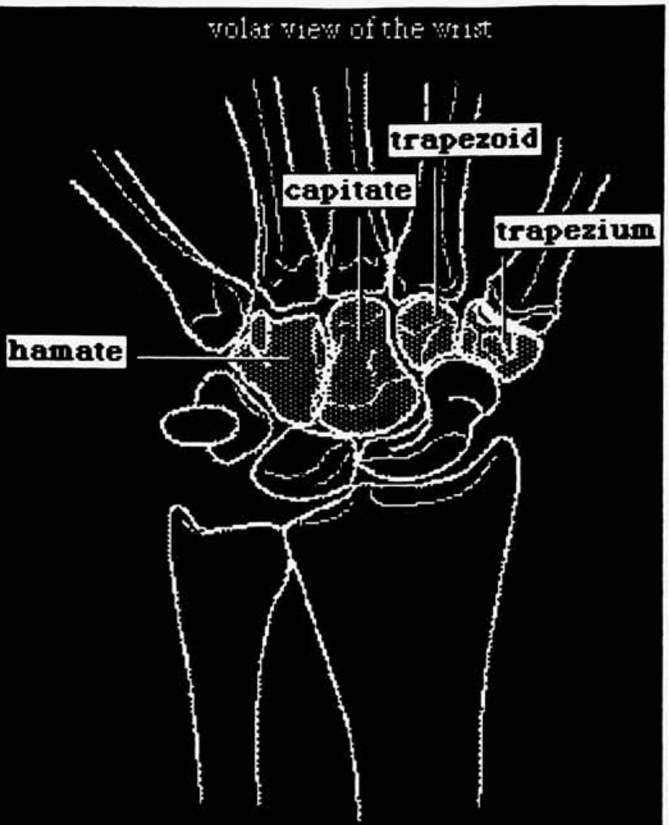
The wrist is a complex anatomic structure which includes the carpo-metacarpal joint (distally), the carpals and all of their articulations, the radiocarpal joint, and all of the structures within the ulnocarpal space. The distal radius may be regarded as part of the wrist since injuries to the distal radius often affect wrist motion. The radio-ulnar joint, however, is more properly considered part of the forearm .

The Wrist: A Basic Review



The carpal bones are arranged in two rows, one proximal and one distal. The proximal row includes (from medial to lateral) the scaphoid, lunate, triquetrum, and pisiform. The bones of the proximal row articulate proximally with the radius and the structures of the ulnocarpal space, and distally with the distal row bones.

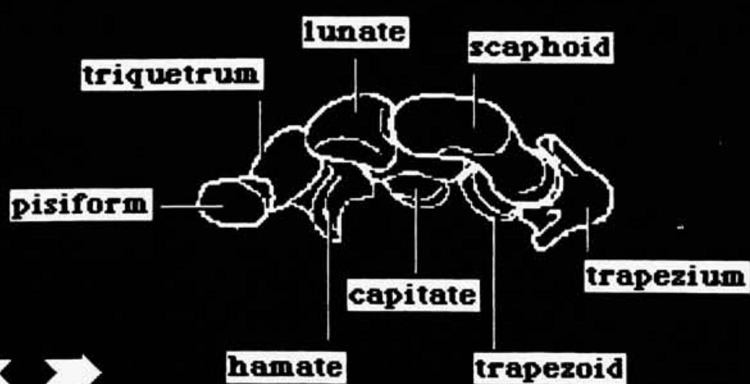
The Wrist: A Basic Review



The distal row includes (medial to lateral) the trapezium, trapezoid, capitate, and hamate. The distal row articulates with the proximal row to form the mid-carpal joint. Distally, the distal row bones articulate with the metacarpals.

The Wrist: A Basic Review

It is important to keep in mind that the carpal bones do not lie flat in the frontal plane. Rather, both the proximal and distal rows form a prominent arch with the concavity (carpal tunnel) facing volarly.



Terminology of Wrist Movements

The movements of the wrist have traditionally been defined in terms of hand motion relative to the long axis of the forearm. These definitions are as follows:

Flexion/Extension: antero-posterior rotation of the carpus about an axis which is perpendicular to the long axis of the forearm and which lies in the frontal plane.

Radial/Ulnar Deviation: medial-lateral rotation of the carpus about an axis which is perpendicular to the long axis of the forearm and which lies in a para-sagittal plane

Pronation/Supination: rotation of the carpus about the long axis of the forearm

Terminology of Wrist Movements

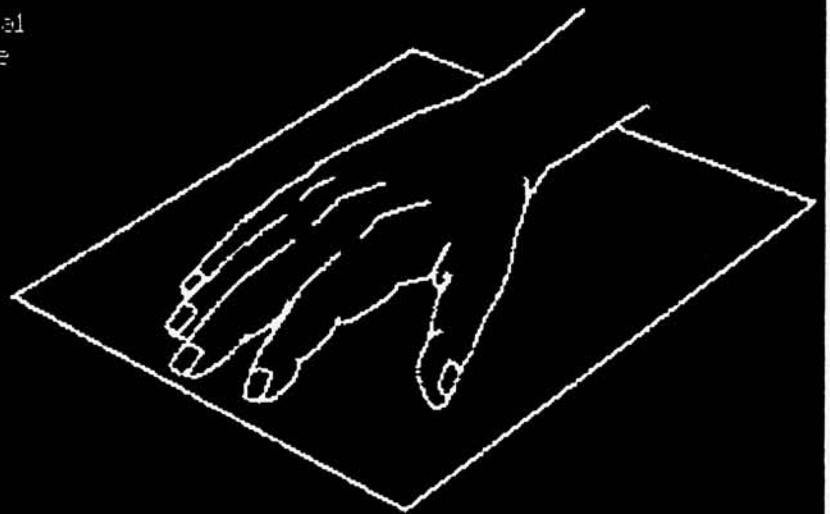
While these definitions are adequate for describing a single motion of the carpus relative to the forearm, they become ambiguous when more than one motion is involved.

Consider, for example, a hand which is flexed 90° relative to the forearm. If this hand is then radially deviated while remaining flexed, the resulting motion would involve lateral rotation of the carpus about the long axis of the forearm. According to the traditional definitions, this would be supination. Yet from a kinematic point of view (and with respect to carpal motion) this latter movement is still radial deviation.

A new set of definitions of wrist movements is called for.

Terminology of Wrist Movements

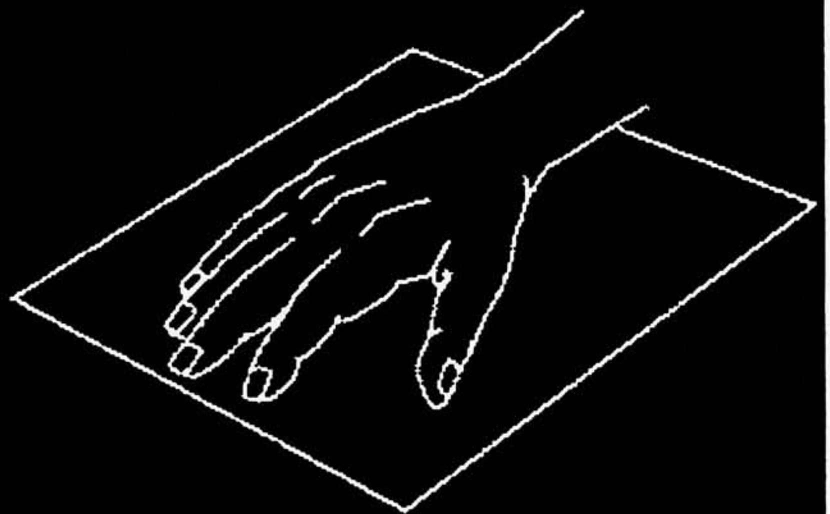
Imagine a hand in the neutral position lying in a flat plane (In anatomical position this would be the frontal plane)



Terminology of Wrist Movements

Flexion and extension of the wrist follows the traditional definition but we can imagine that this plane flexes and extends with the carpus such that the axis of the long finger remains fixed within the plane

Click on the hand to observe this motion.



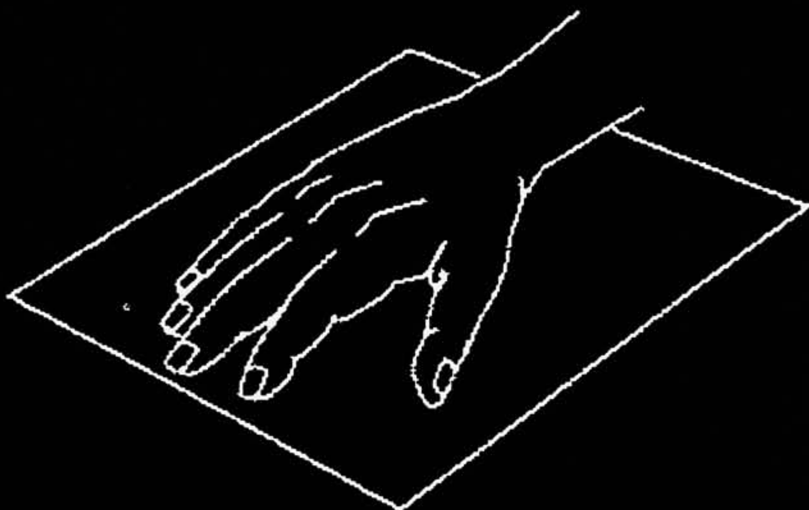
Terminology of Wrist Movements

Flexion and extension of the wrist follows the traditional definition, but we can imagine that this plane flexes and extends with the carpus such that the axis of the long finger remains fixed within the plane.

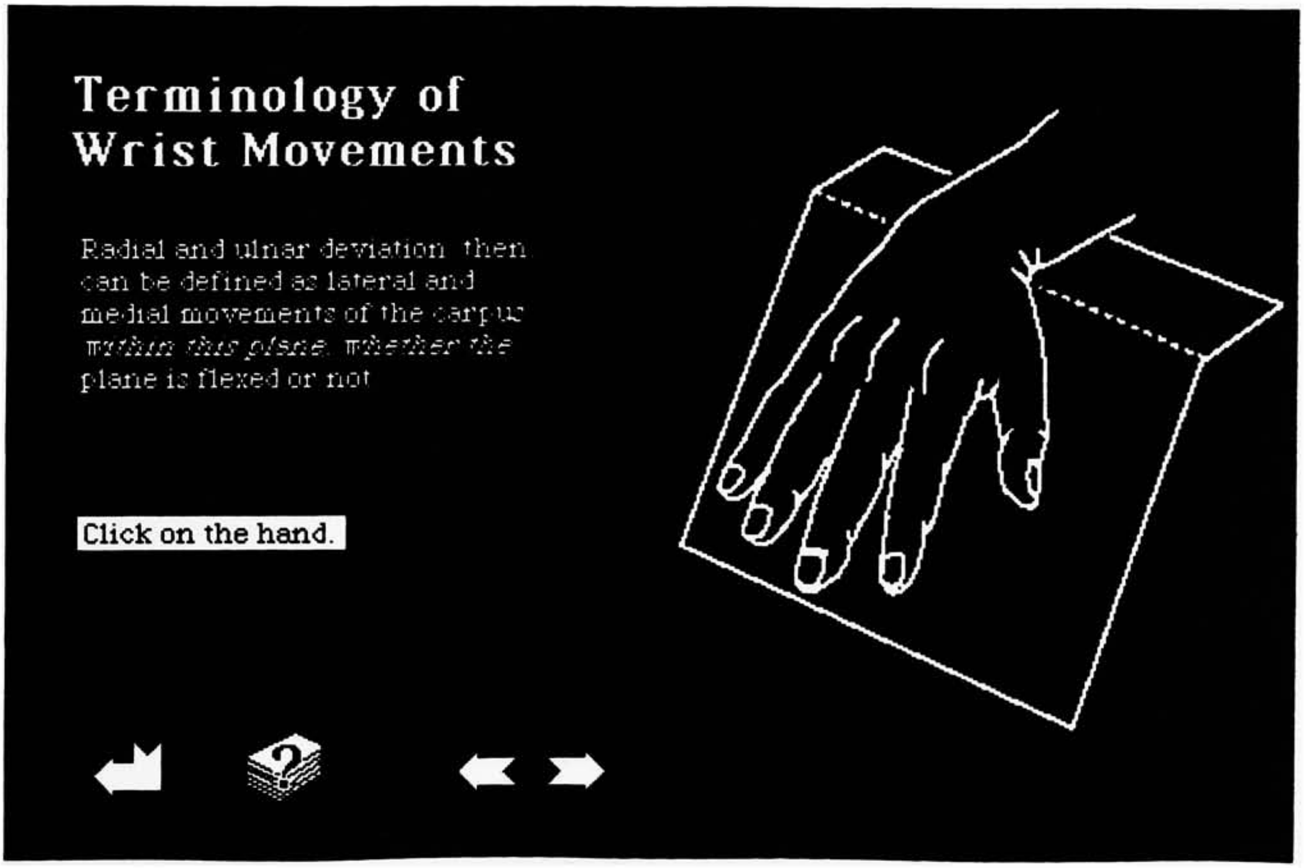
Extension

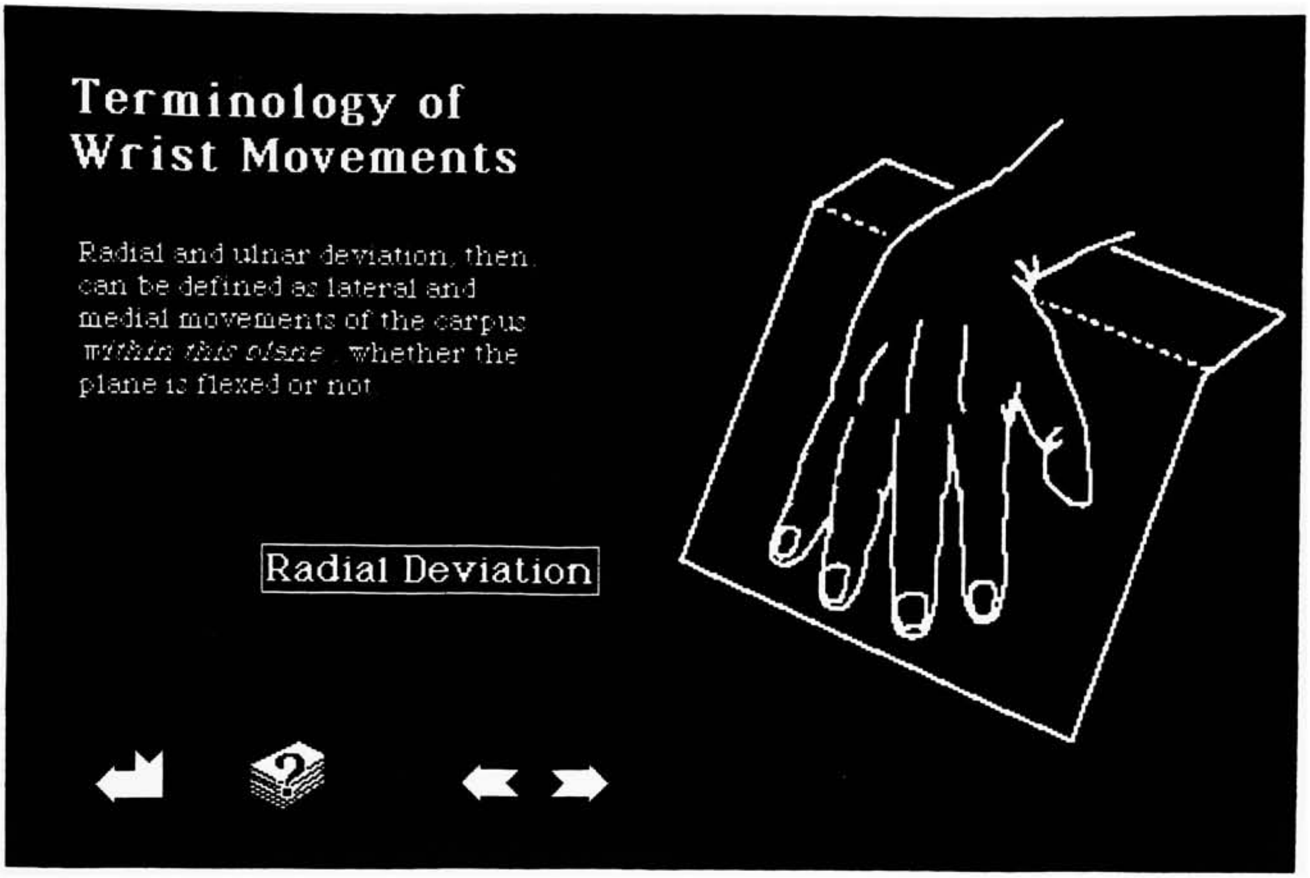
Terminology of Wrist Movements

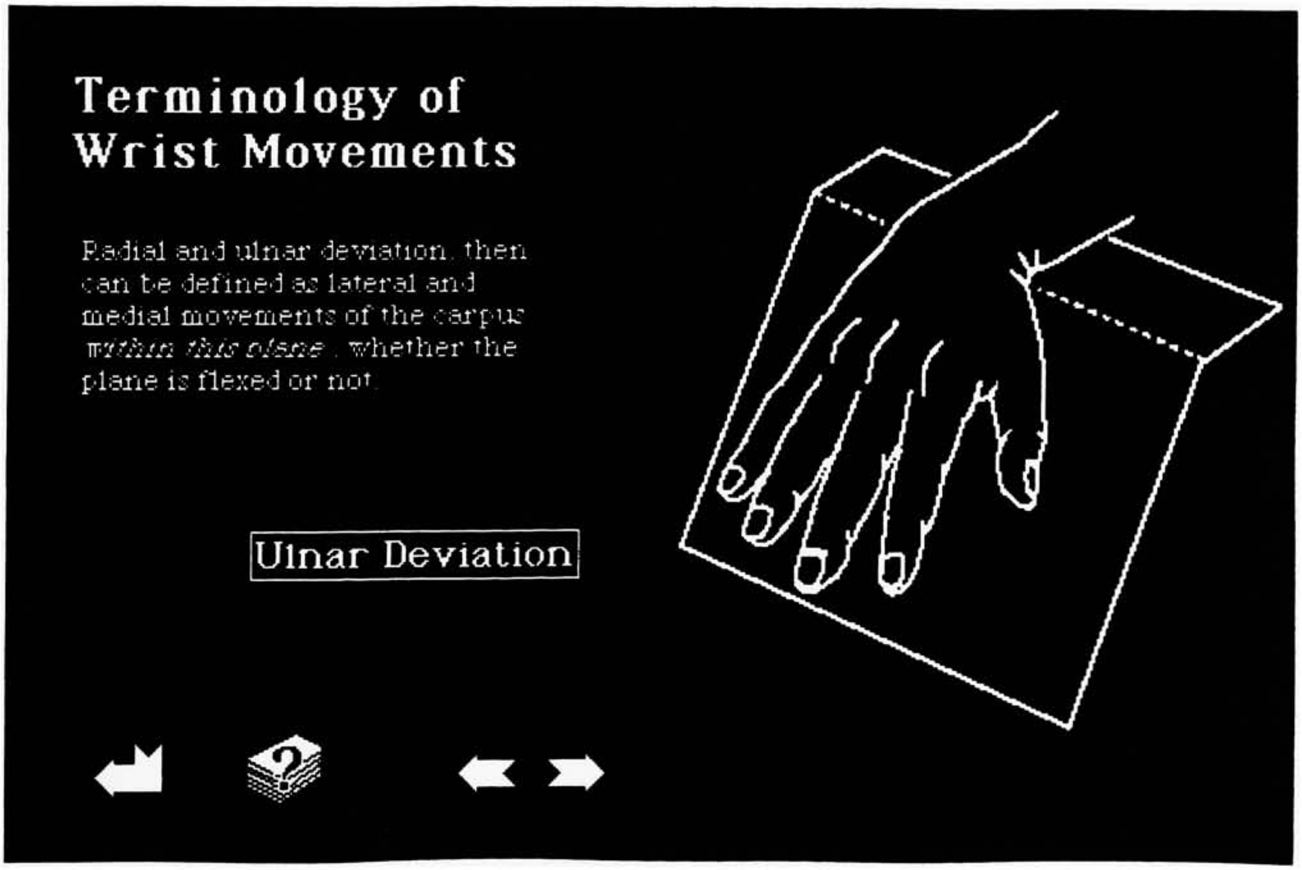
Flexion and extension of the wrist follows the traditional definition, but we can imagine that this plane flexes and extends with the carpus such that the axis of the long finger remains fixed within the plane.




Terminology of
Wrist Movements
Flexion and extension of the wrist follows the traditional definition, but we can imagine that this plane flexes and extends with the carpus such that the axis of the long finger remains fixed within the plane.
Flexion
(Note: in the healthy wrist, flexion always involves a significant degree of ulnar deviation.)


Terminology of
Wrist Movements
Radial and ulnar deviation, then, can be defined as lateral and medial movements of the carpus within this plane, whether the plane is flexed or not.
Click on the hand.

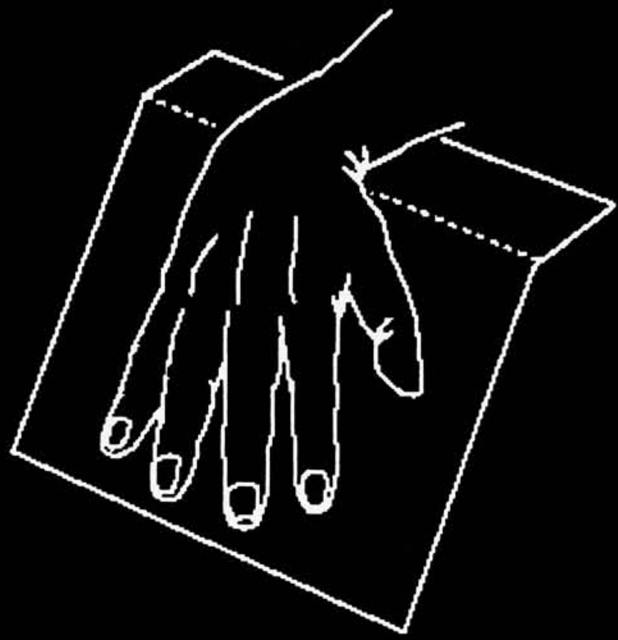

Terminology of
Wrist Movements
Radial and ulnar deviation, then, can be defined as lateral and medial movements of the carpus *within this plane*, whether the plane is flexed or not.
Radial Deviation


Terminology of
Wrist Movements
Radial and ulnar deviation, then, can be defined as lateral and medial movements of the carpus *within this plane*, whether the plane is flexed or not.
Ulnar Deviation

Terminology of Wrist Movements

Radial and ulnar deviation, then, can be defined as lateral and medial movements of the carpus *within this plane*, whether the plane is flexed or not.

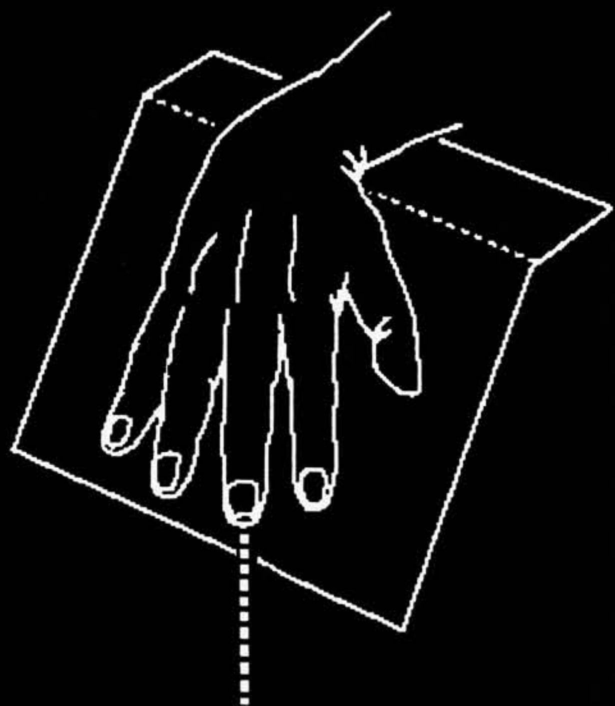
Radial Deviation

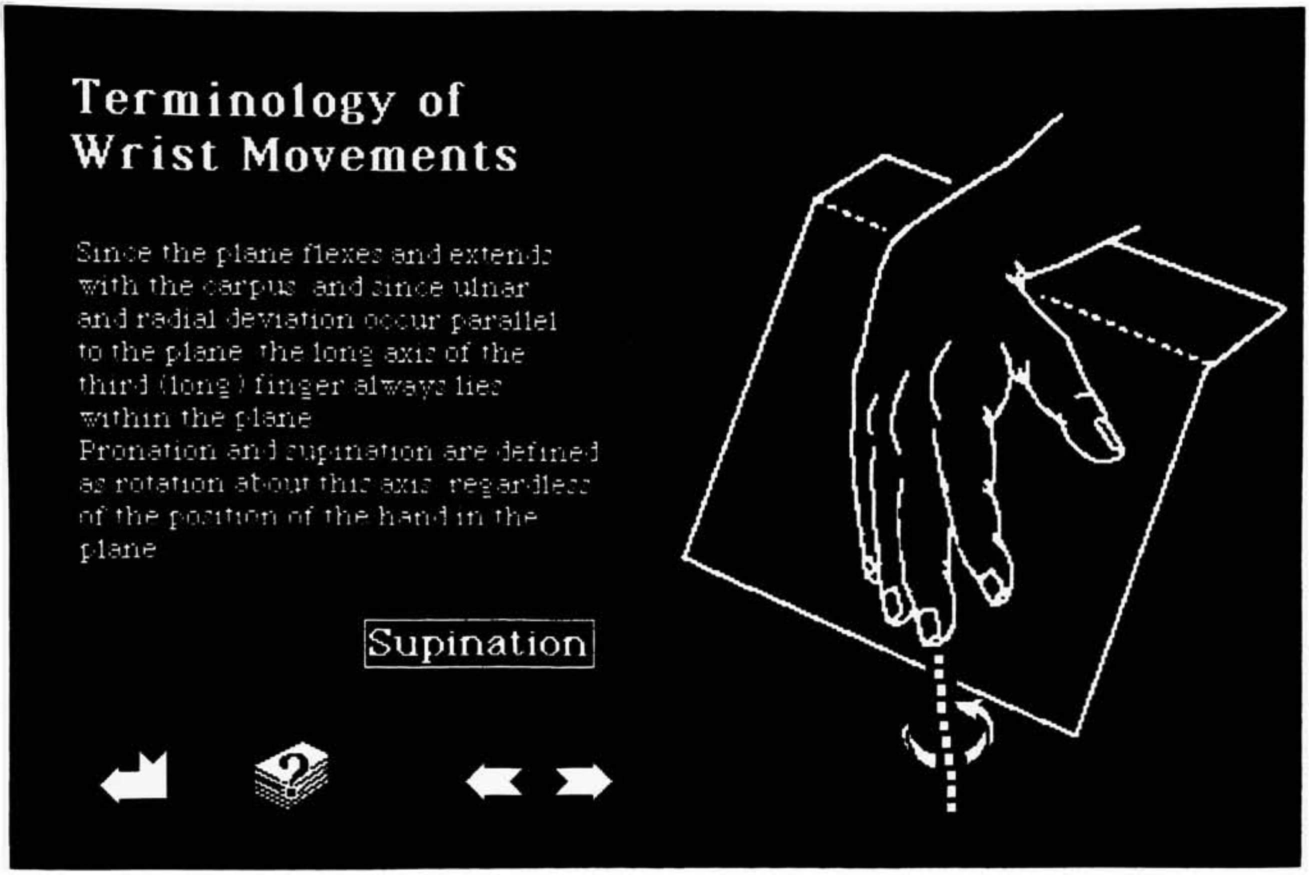


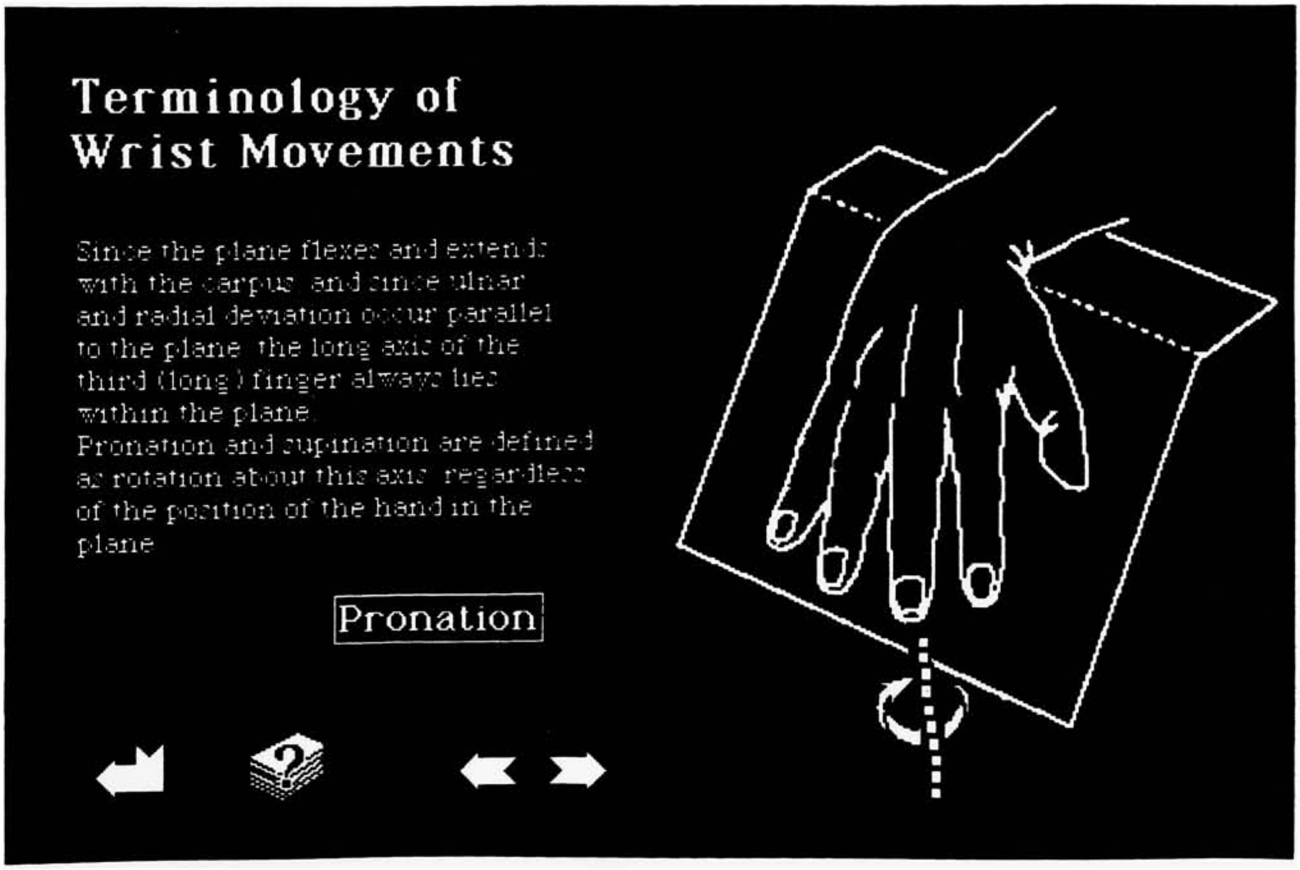
Terminology of Wrist Movements

Since the plane flexes and extends with the carpus, and since ulnar and radial deviation occur parallel to the plane, the long axis of the third (long) finger always lies within the plane.
Pronation and supination are defined as rotation about this axis, regardless of the position of the hand in the plane

Click on the hand.




Terminology of Wrist Movements
Since the plane flexes and extends with the carpus and since ulnar and radial deviation occur parallel to the plane the long axis of the third (long) finger always lies within the plane
Pronation and supination are defined as rotation about this axis regardless of the position of the hand in the plane
Supination


Terminology of Wrist Movements
Since the plane flexes and extends with the carpus and since ulnar and radial deviation occur parallel to the plane the long axis of the third (long) finger always lies within the plane.
Pronation and supination are defined as rotation about this axis regardless of the position of the hand in the plane
Pronation

Movements of the Wrist

Degrees of Freedom

The movement of one object relative to another such as occurs at a joint can be described by six different parameters or "degrees of freedom". These parameters consist of three for angular movements (antero-posterior angular projection, lateral angular projection, and rotation) and three for translational displacement (antero-posterior projection, lateral projection, and distraction-override).

Movements of the Wrist

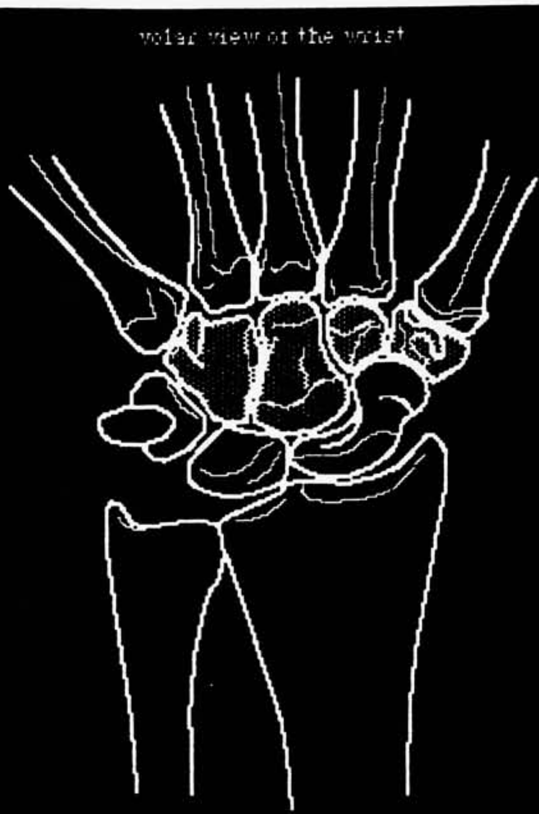
Degrees of Freedom

Thus, the motion of one bone relative to another at a joint (or two pieces of a single bone in the event of a fracture) must be described by six different parameters or degrees of freedom. Most joints are constrained against certain types of motion and can be described as having fewer degrees of freedom. The PIP joint of the finger, for example is constrained to a single type of motion - antero-posterior angular displacement - and therefore has a single degree of freedom.
The wrist, however is much more complex. The motion of the wrist represents the sum of the motion of multiple smaller joints, i.e. all of the articulations of the carpal bones with one another and with the radius. There is the potential for 48 degrees of freedom (six degrees times eight bones) in the movement of the wrist.

Movements of the Wrist

Simplifying Concepts

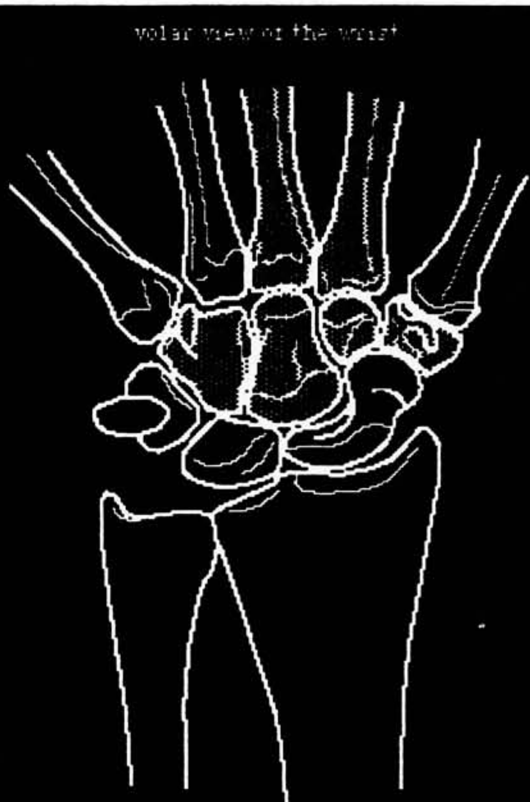
Fortunately, there are several anatomic constraints which greatly simplify the movements of the wrist.
First of all, the intrinsic interosseous ligaments of the distal row join these bones so tightly that they function as a single, solid unit.



Movements of the Wrist

Simplifying Concepts

The distal row bones are also tightly bound to the index and long finger metacarpals. Thus, these two meta-carpals, along with the trapezium, trapezoid, capitate, and hamate form a "fixed unit" which can be considered as a single segment during all wrist movements.

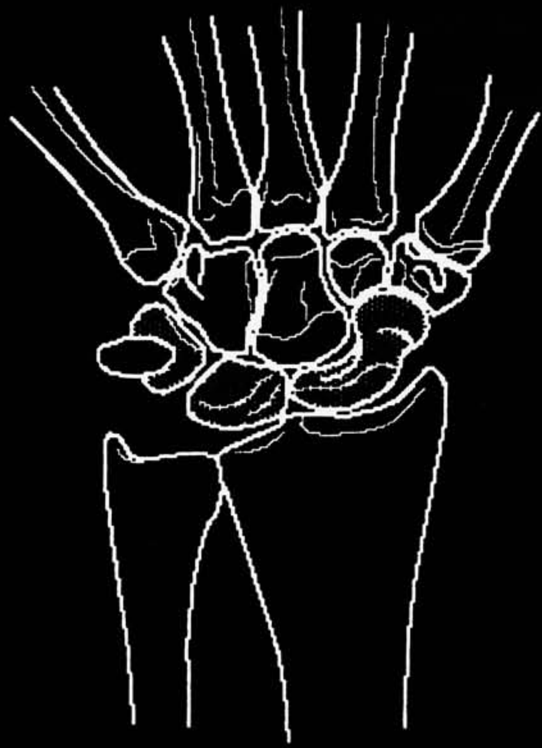


Movements of the Wrist

Simplifying Concepts

The bones of the proximal row are also linked to one another by inter-osseous ligaments and tend to move in unison, though a certain amount of relative motion is permitted.

volar view of the wrist



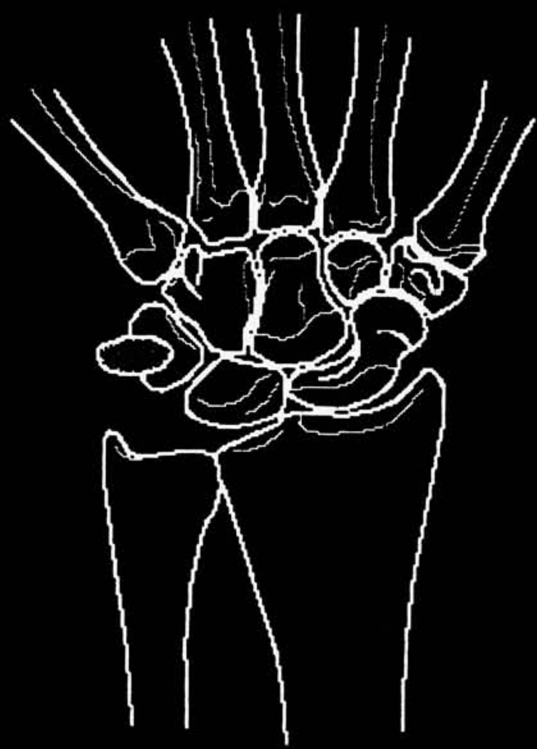
Movements of the Wrist

Simplifying Concepts

The pisiform bone is a sesamoid within the flexor carpi ulnaris tendon and is probably of little importance in the kinematics of the wrist.

Thus, from a kinematic perspective the wrist consists of the radius proximally, the fixed unit distally, and the three proximal row bones inter-calated in between.

volar view of the wrist

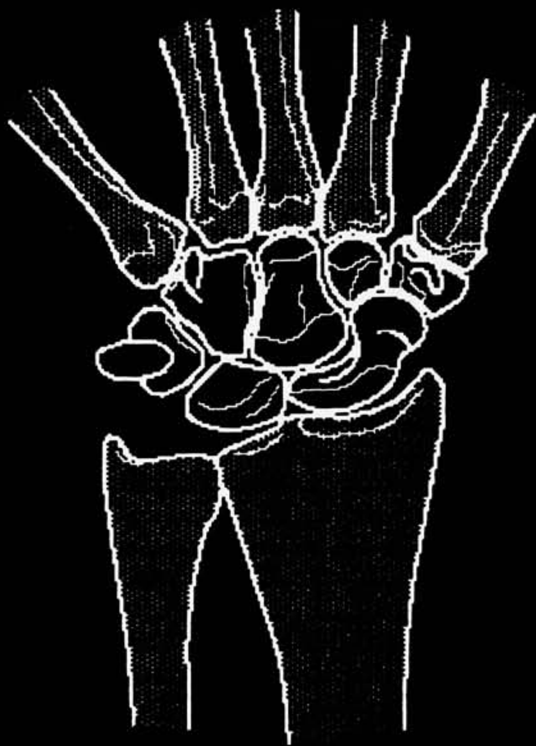


Movements of the Wrist

Simplifying Concepts

All of the muscles which control the movement of the wrist and fingers originate proximal to the wrist (i.e. in the forearm) and insert distal to the wrist (i.e. on the metacarpals or phalanges). Not a single muscle originates or inserts on the carpals (the pisiform, embedded in the ECU tendon, may be considered an exception to this rule).

volar view of the wrist

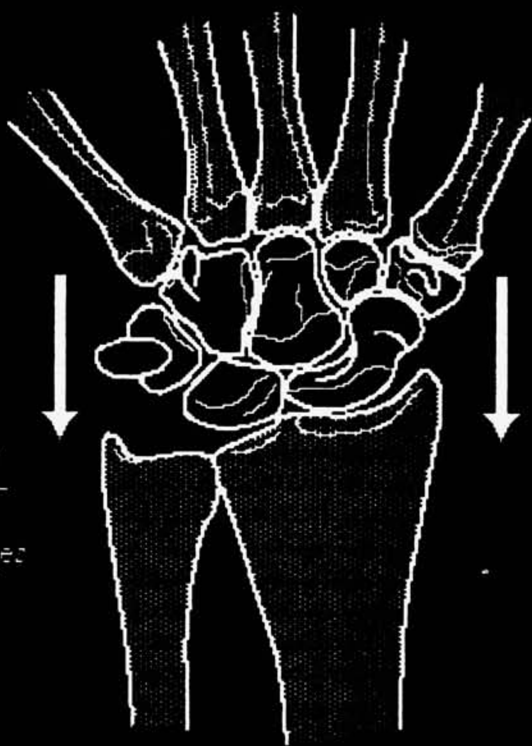


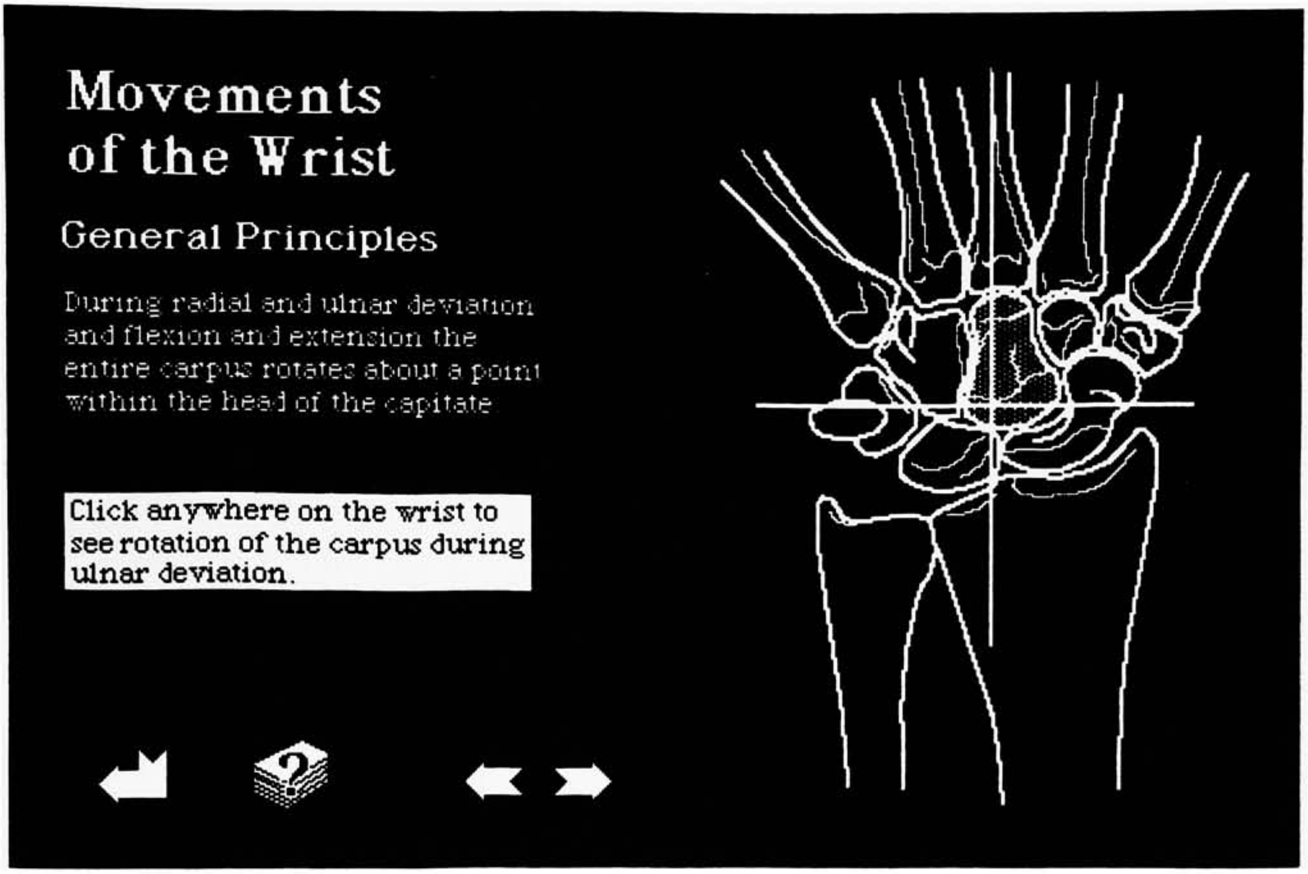
Movements of the Wrist

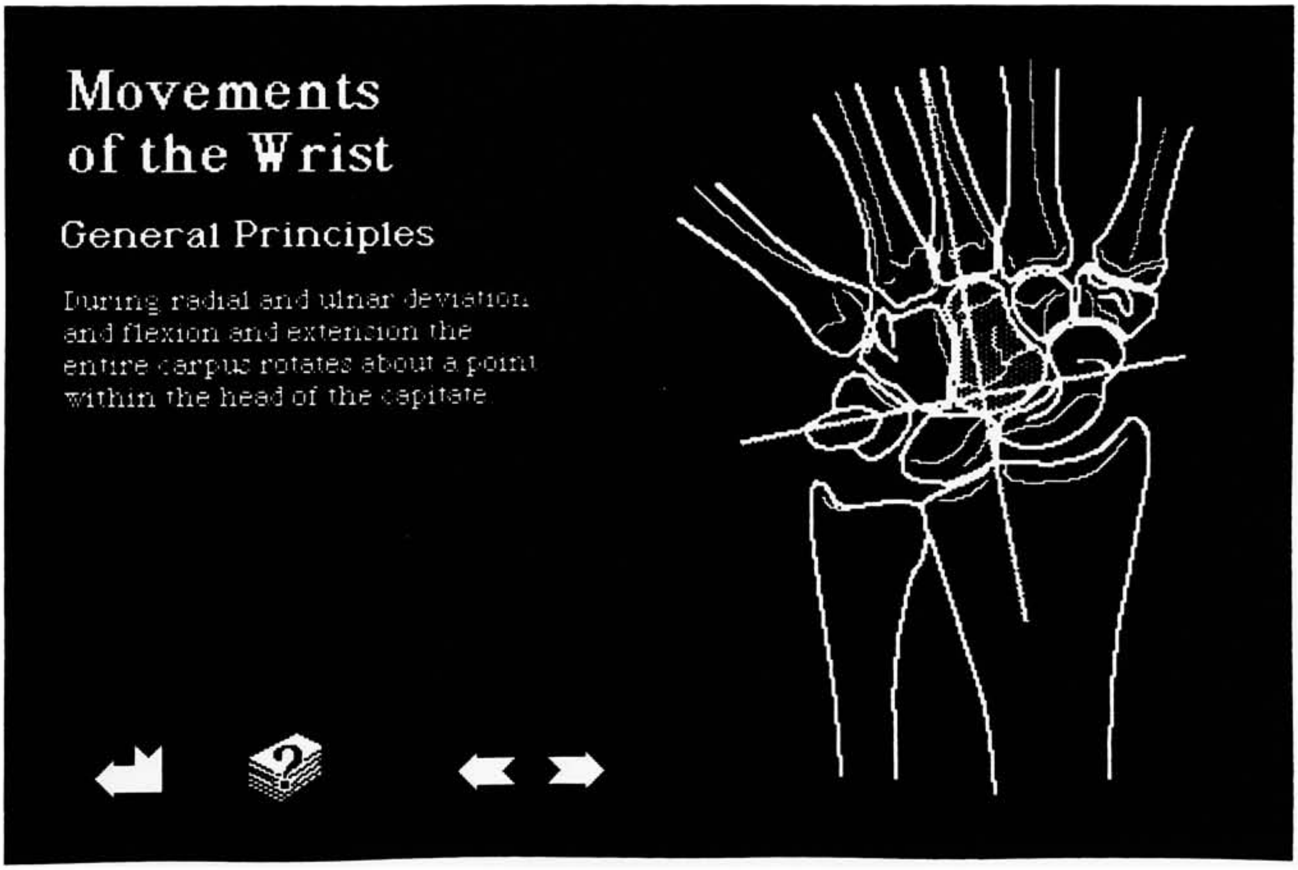
Simplifying Concepts

Contraction of the muscles on the dorsal, volar, radial, or ulnar sides of the forearm leads to extension, flexion, radial, or ulnar deviation, respectively. The distal row moves in concert with the rest of the carpus. The proximal row, intercalated between the fixed unit and radius, is "squeezed" when the carpus is drawn proximally during any of these movements. The movement of the proximal row is controlled by the shape of the articular surfaces with which it interacts and by the direction of forces applied to it by the moving carpus.

volar view of the wrist




Movements
of the Wrist
General Principles
During radial and ulnar deviation and flexion and extension the entire carpus rotates about a point within the head of the capitate.
Click anywhere on the wrist to see rotation of the carpus during ulnar deviation.


Movements
of the Wrist
General Principles
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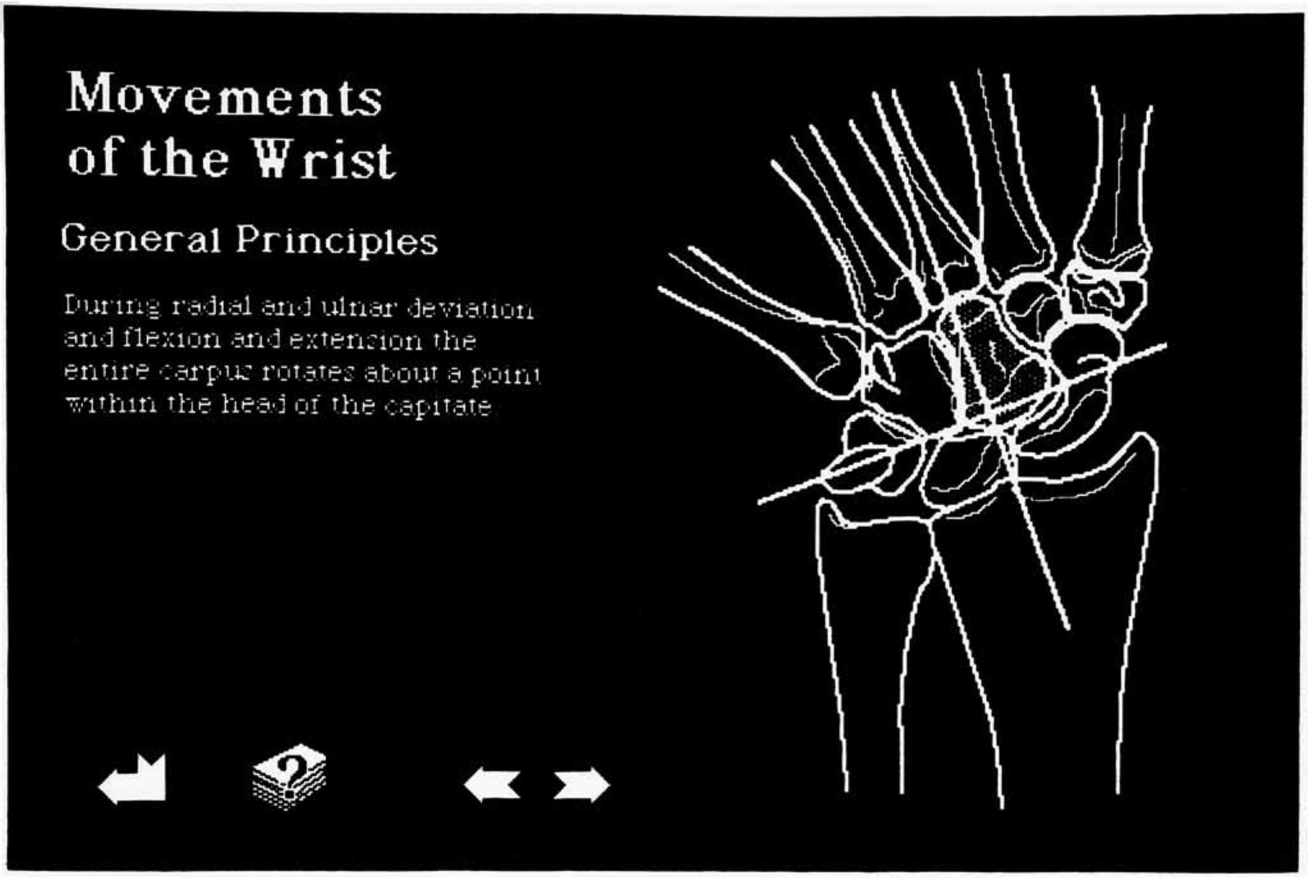

Movements
of the Wrist
General Principles
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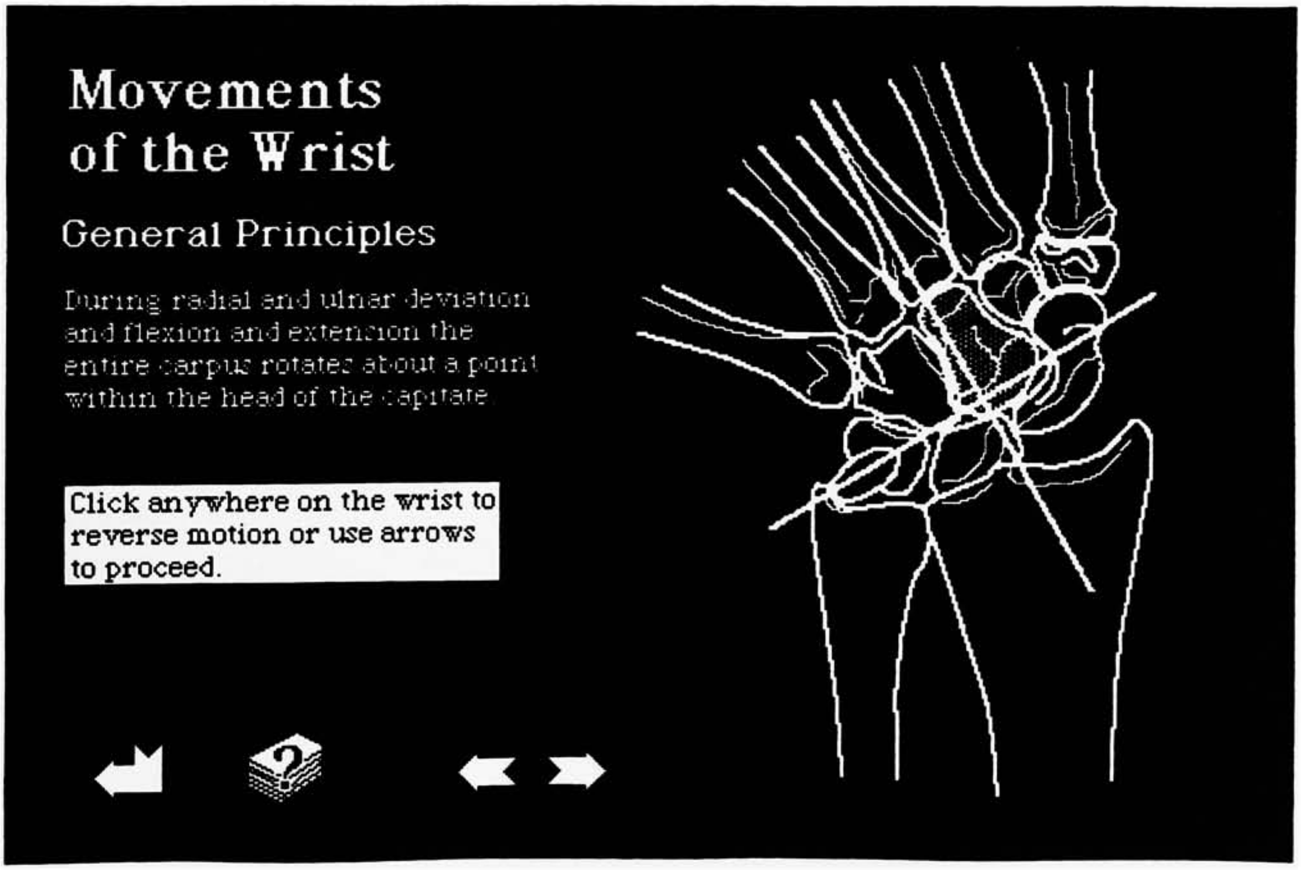
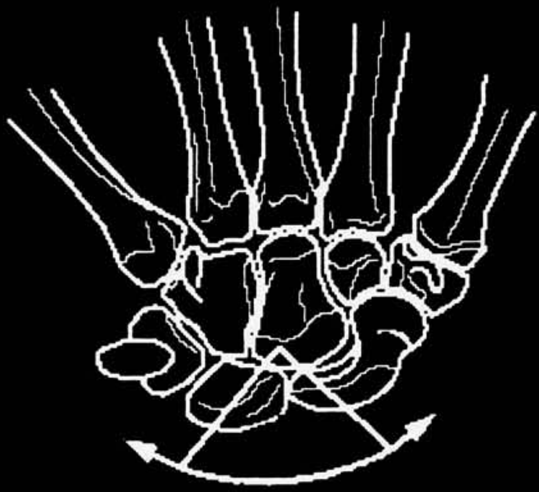


Movements
of the Wrist
General Principles
During radial and ulnar deviation and flexion and extension the entire carpus rotates about a point within the head of the capitate.
Click anywhere on the wrist to reverse motion or use arrows to proceed.

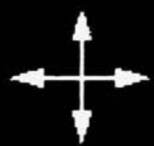
Movements of the Wrist

General Principles

Thus, all translational movements of the proximal row bones in the coronal plane (i.e. medial-lateral and proximal-distal translation) occur along the circumference of a circle centered within the head of the capitate.



Translational axes



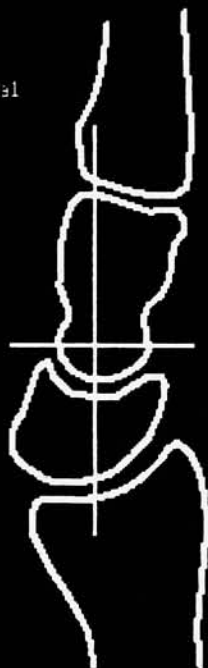
Movements of the Wrist

General Principles

Para-sagittal section of the wrist

The head of the capitate also acts as the center of rotation for the carpus during flexion and extension. The proximal row bones move relative to the radius travelling in an arc centered about the capitate. There is also motion at the mid-carpal joint - the fixed unit rotating relative to the proximal row.

Click on the wrist to see this motion during flexion.



Para-sagittal section of the wrist

Movements of the Wrist

General Principles

The head of the capitate also acts as the center of rotation for the carpus during flexion and extension. The proximal row bones move relative to the radius travelling in an arc centered about the capitate. There is also motion at the mid-carpal joint – the fixed unit rotating relative to the proximal row.

Para-sagittal section of the wrist

Movements of the Wrist

General Principles

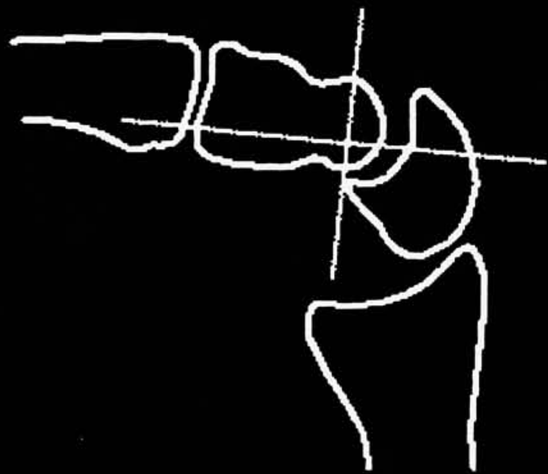
The head of the capitate also acts as the center of rotation for the carpus during flexion and extension. The proximal row bones move relative to the radius travelling in an arc centered about the capitate. There is also motion at the mid-carpal joint – the fixed unit rotating relative to the proximal row.

Movements of the Wrist

General Principles

The head of the capitate also acts as the center of rotation for the carpus during flexion and extension. The proximal row bones move relative to the radius travelling in an arc centered about the capitate. There is also motion at the mid-carpal joint - the fixed unit rotating relative to the proximal row.

Click on the wrist to reverse motion or use arrows to proceed



Movements of the Wrist

General Principles

Thus, all antero-posterior translational movements (i.e. motion in the sagittal plane) of the fixed unit and proximal row occur along the circumference of circles centered around the head of the capitate.

Movements of the Wrist

General Principles

The bones of the proximal row articulate proximally with the distal end of the radius. The articulating surface of the radius slopes volarly such that when the carpals are drawn towards the radius by axial forces there is a tendency for the proximal row bones to slide volarly into an extended (dorsiflexed) position.
This is precisely what happens during extension and ulnar deviation - the entire proximal row shifts volarly and extends.

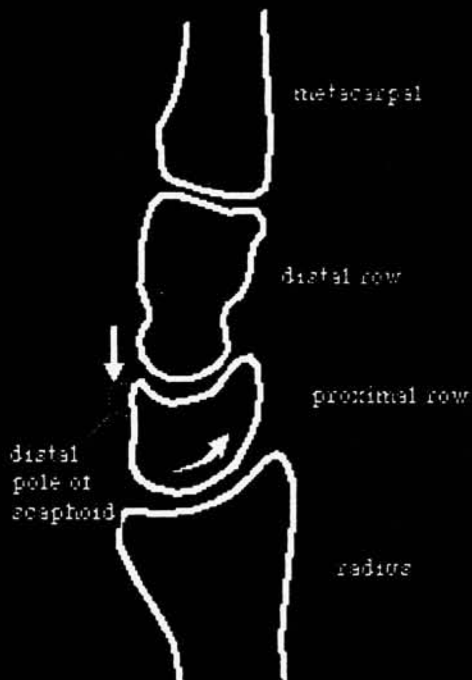
Para-sagittal section of the wrist

Movements of the Wrist

General Principles

During flexion and radial deviation, however the tendency of the proximal row to extend is counteracted by movements of the scaphoid. The distal pole of the scaphoid points distally and volarly. During flexion and radial deviation, the trapezium-trapezoid complex is drawn towards the radius and pushes the distal pole of the scaphoid proximally and dorsally, forcing the scaphoid into a flexed position. Because of their interosseous connections, this motion of the scaphoid forces the other proximal carpals into flexion as well, despite their inherent tendency to extend.

Para-sagittal section of the wrist

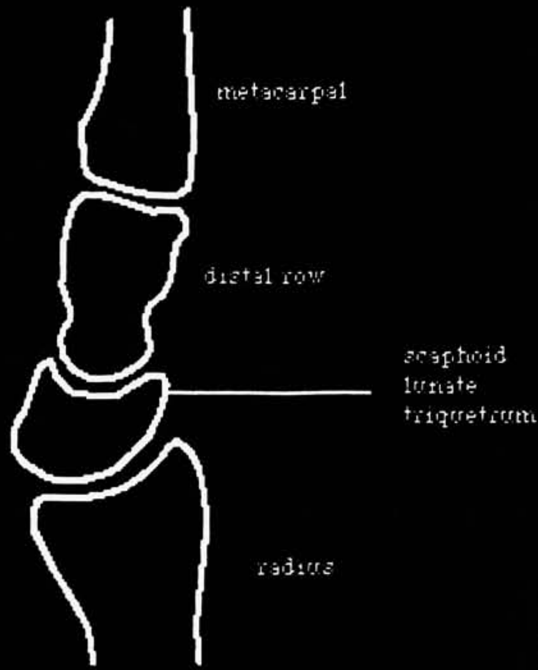


Para-sagittal section of the wrist

Movements of the Wrist

General Principles

Even though the proximal row bones tend to move in the same direction due to their interosseous connections, these connections are not perfectly rigid. Thus, there is some relative motion between the proximal carpals. In particular, there is a slight difference in the extent to which these bones flex and extend during movements of the wrist.



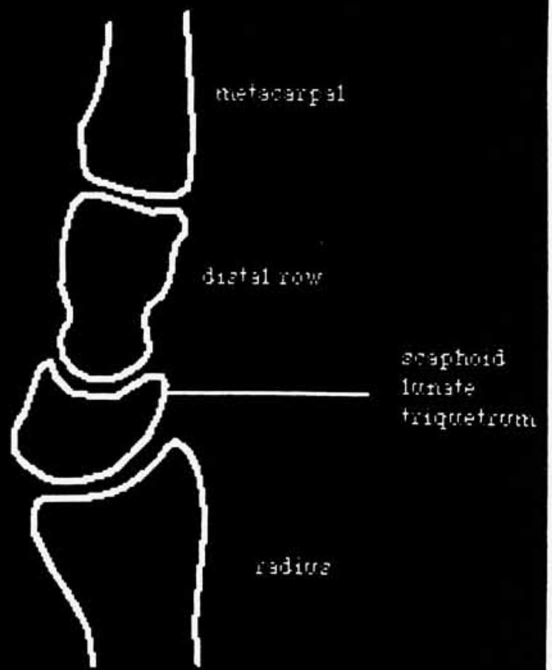
Para-sagittal section of the wrist

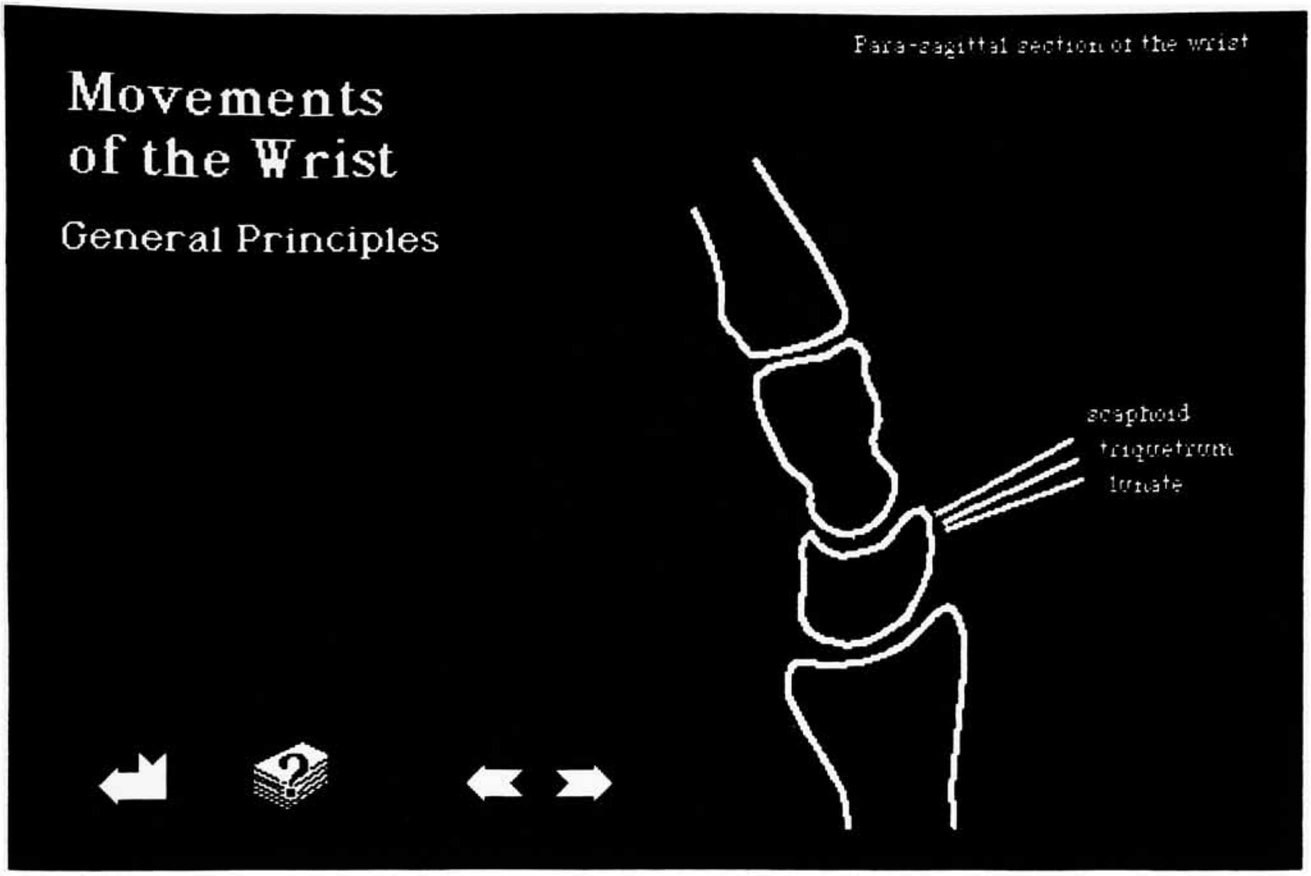
Movements of the Wrist

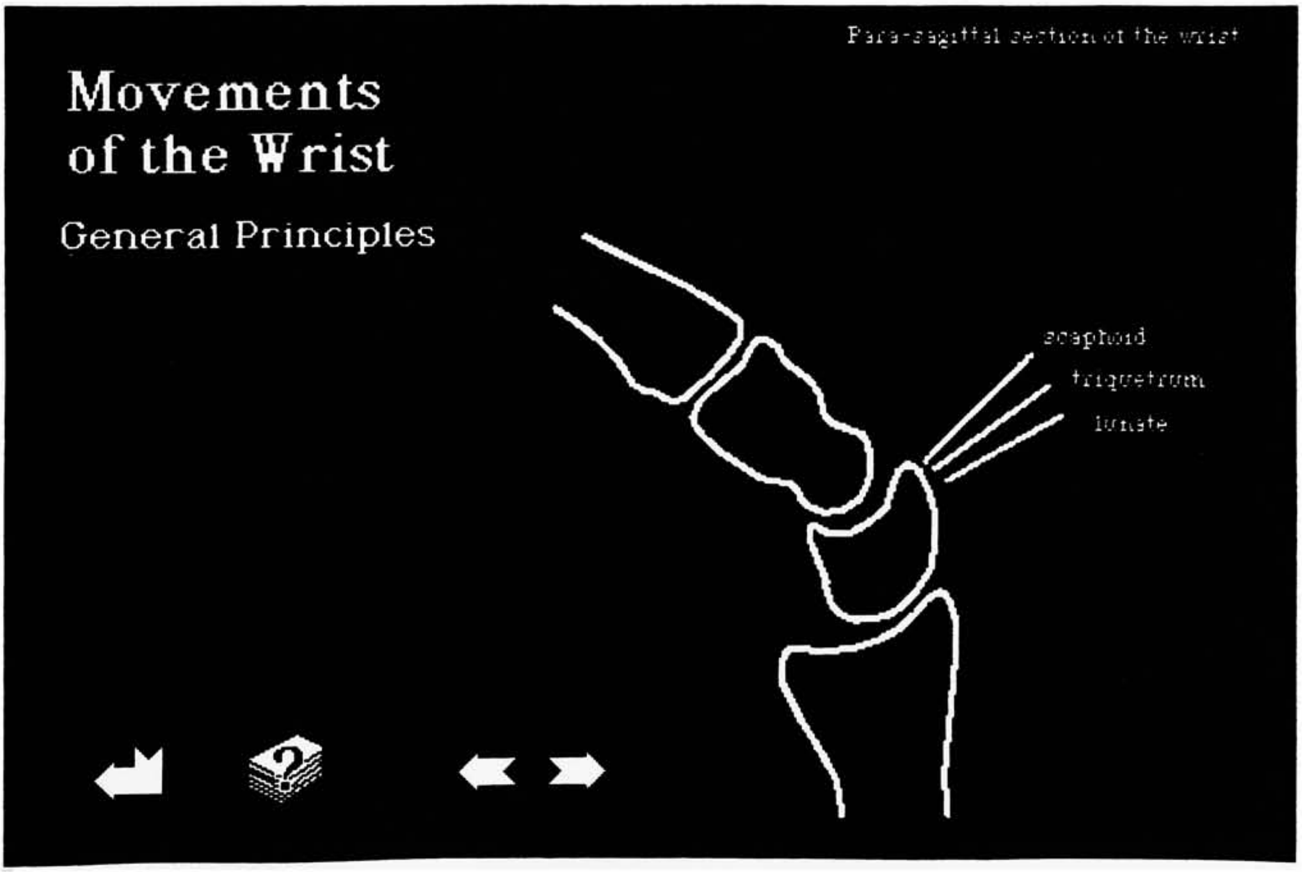
General Principles

It is possible to demonstrate the different degrees of movement of the proximal row bones by inserting Kirschner wires directly into the scaphoid, lunate and triquetrum of an appropriately dissected cadaver wrist. This illustration shows a cross-section of a wrist in the neutral position with the three wires aligned.

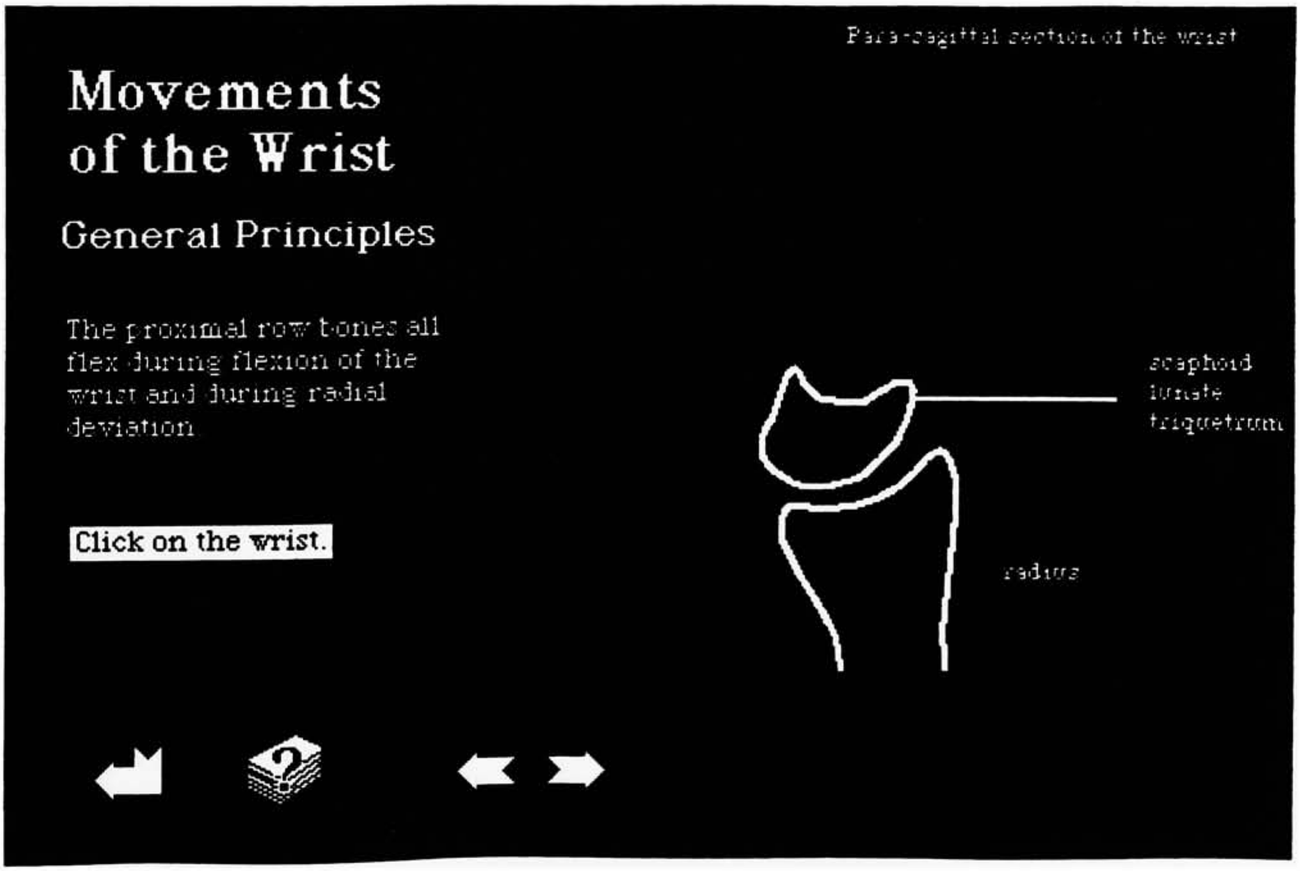
Click on the wrist to observe relative motion of the proximal carpals during flexion.




Para-sagittal section of the wrist
Movements of the Wrist
General Principles
scaphoid
triquetrum
lunate


Para-sagittal section of the wrist
Movements of the Wrist
General Principles
scaphoid
triquetrum
lunate

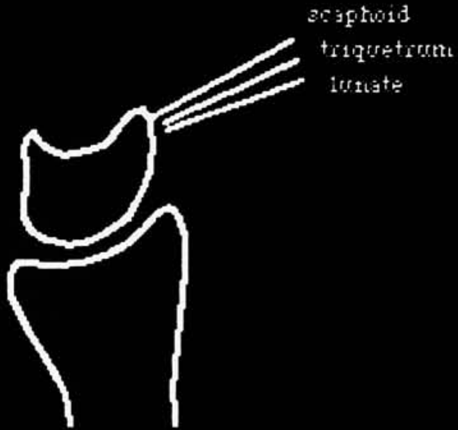

Para-sagittal section of the wrist
Movements
of the Wrist
General Principles
Note that the scaphoid moves the most, then the triquetrum, and the lunate moves the least. This holds true for all movements of the wrist (barring any pathology).
Click on the wrist to reverse or use arrows to proceed.
scaphoid
triquetrum
lunate


Para-sagittal section of the wrist
Movements
of the Wrist
General Principles
The proximal row bones all flex during flexion of the wrist and during radial deviation.
Click on the wrist.
scaphoid
lunate
triquetrum
radius

Movements of the Wrist

General Principles

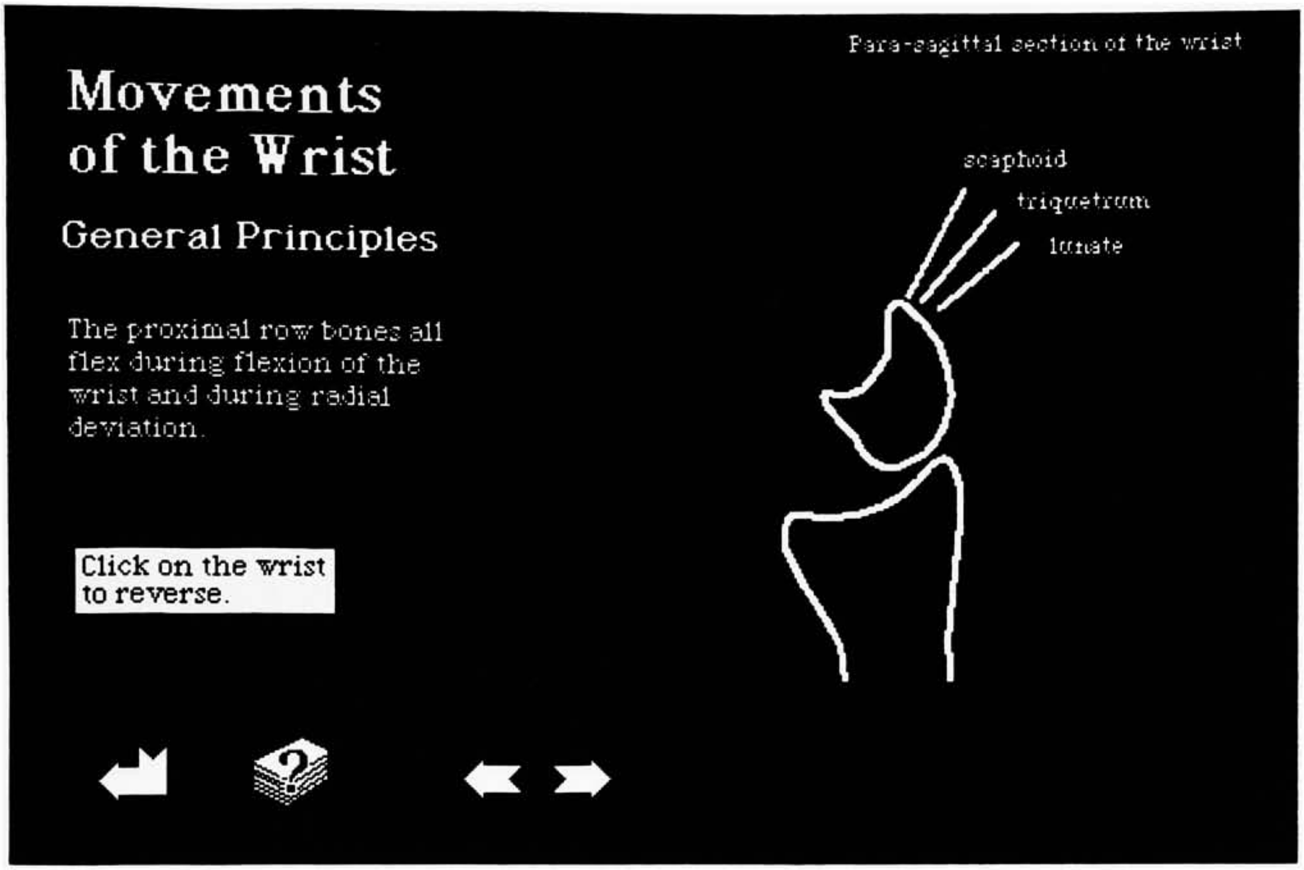
The proximal row bones all flex during flexion of the wrist and during radial deviation

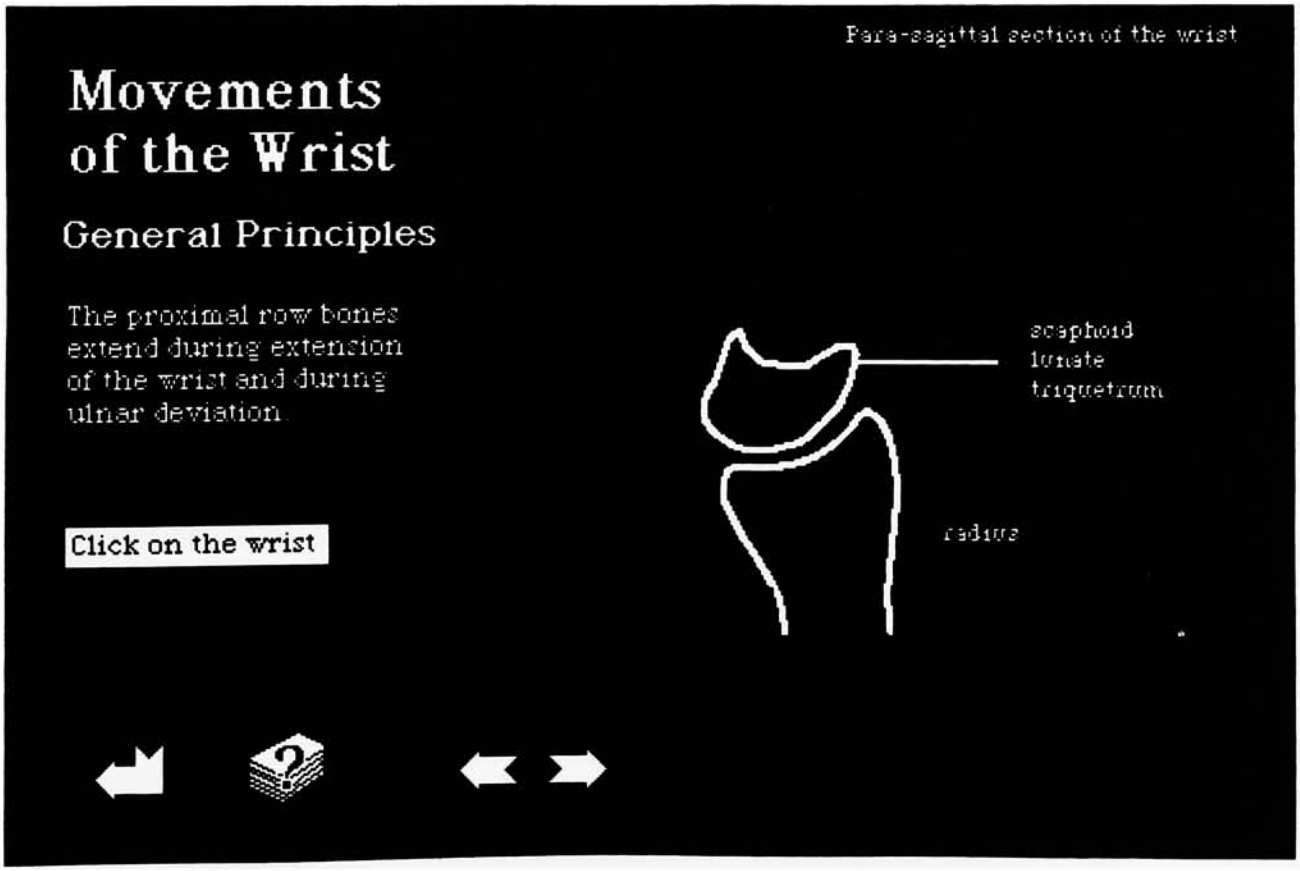


Movements of the Wrist

General Principles

The proximal row bones all flex during flexion of the wrist and during radial deviation.


Para-sagittal section of the wrist
Movements
of the Wrist
General Principles
The proximal row bones all flex during flexion of the wrist and during radial deviation.
Click on the wrist to reverse.
scaphoid
triquetrum
lunate

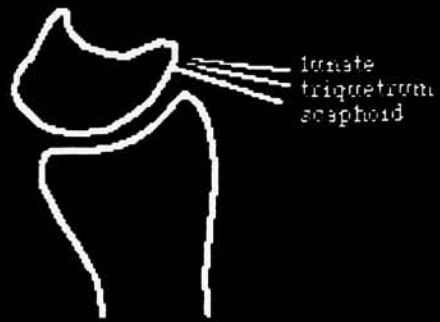

Para-sagittal section of the wrist
Movements
of the Wrist
General Principles
The proximal row bones extend during extension of the wrist and during ulnar deviation.
Click on the wrist
scaphoid
lunate
triquetrum
radius

Para-sagittal section of the wrist

Movements of the Wrist

General Principles

The proximal row bones extend during extension of the wrist and during ulnar deviation.



Para-sagittal section of the wrist

Movements of the Wrist

General Principles

The proximal row bones extend during extension of the wrist and during ulnar deviation.

Click on the wrist to reverse or use arrows to proceed.

Para-sagittal section of the wrist

Movements of the Wrist

General Principles

Notice again that the scaphoid moves the most, then the triquetrum, and the lunate moves the least.

Para-sagittal section of the wrist

Movements of the Wrist

General Principles

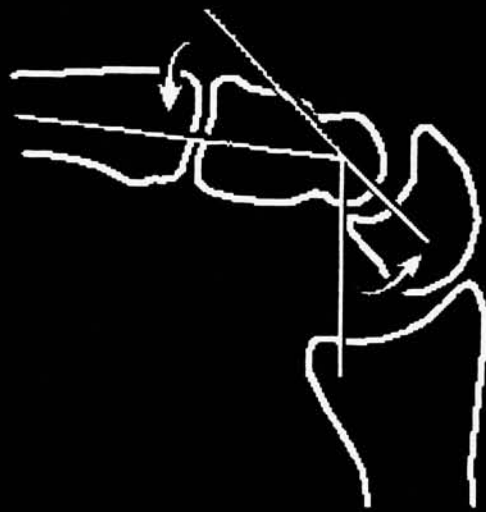
It was noted earlier that during flexion and extension part of the motion occurs at the radiocarpal joint and part occurs at the mid-carpal joint (i.e. between the proximal and distal rows).

Para-sagittal section of the wrist

Movements of the Wrist

General Principles

On average, approximately half of the total range of motion during either flexion or extension occurs at the radiocarpal joint and the other half at the mid-carpal joint.

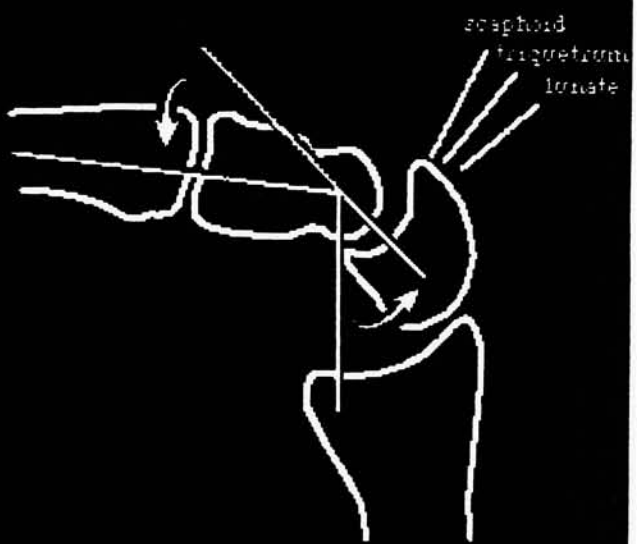


Para-sagittal section of the wrist

Movements of the Wrist

General Principles

However, since the range of motion of each of the proximal row bones differs, the extent to which the proximal row contributes to flexion or extension is somewhat different for each bone.

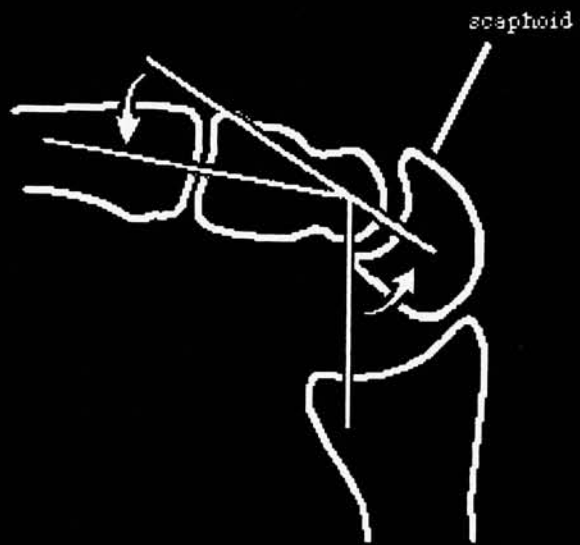


Para-sagittal section of the wrist

Movements of the Wrist

General Principles

If we consider a para-sagittal section through the scaphoid, we see that roughly two-thirds of the motion of either flexion or extension results from translation of the scaphoid and only one-third from motion at the scapho-capitate joint.

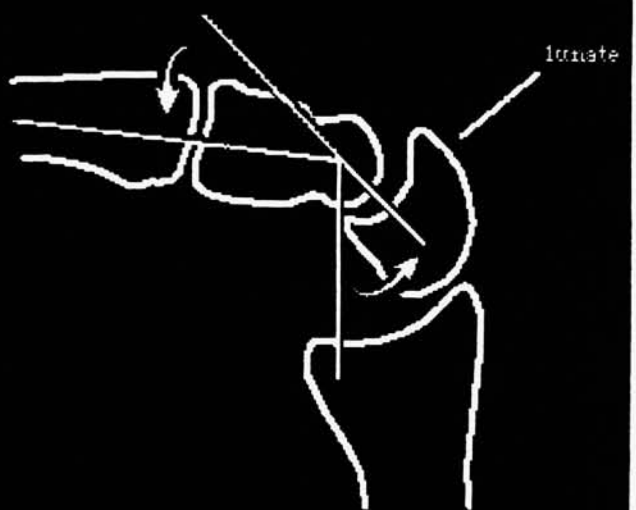


Para-sagittal section of the wrist

Movements of the Wrist

General Principles

The lunate, which moves the least, accounts for just under half of the total motion of flexion or extension.

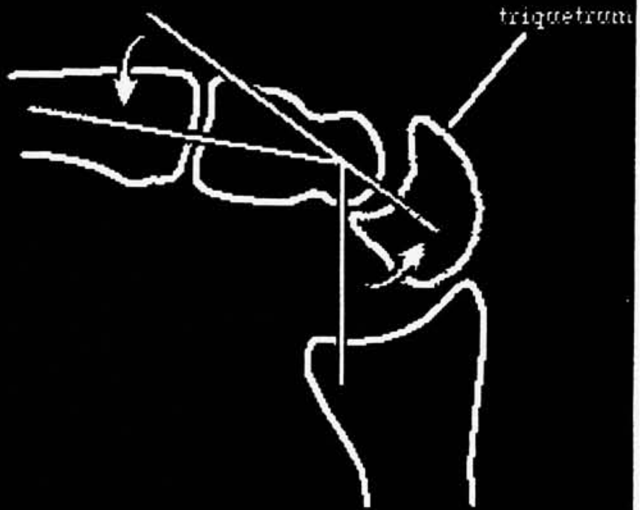


Movements of the Wrist

General Principles

The triquetrum, whose range of motion is intermediate between that of the scaphoid and lunate, accounts for 55 - 60 % of the motion of flexion or extension.

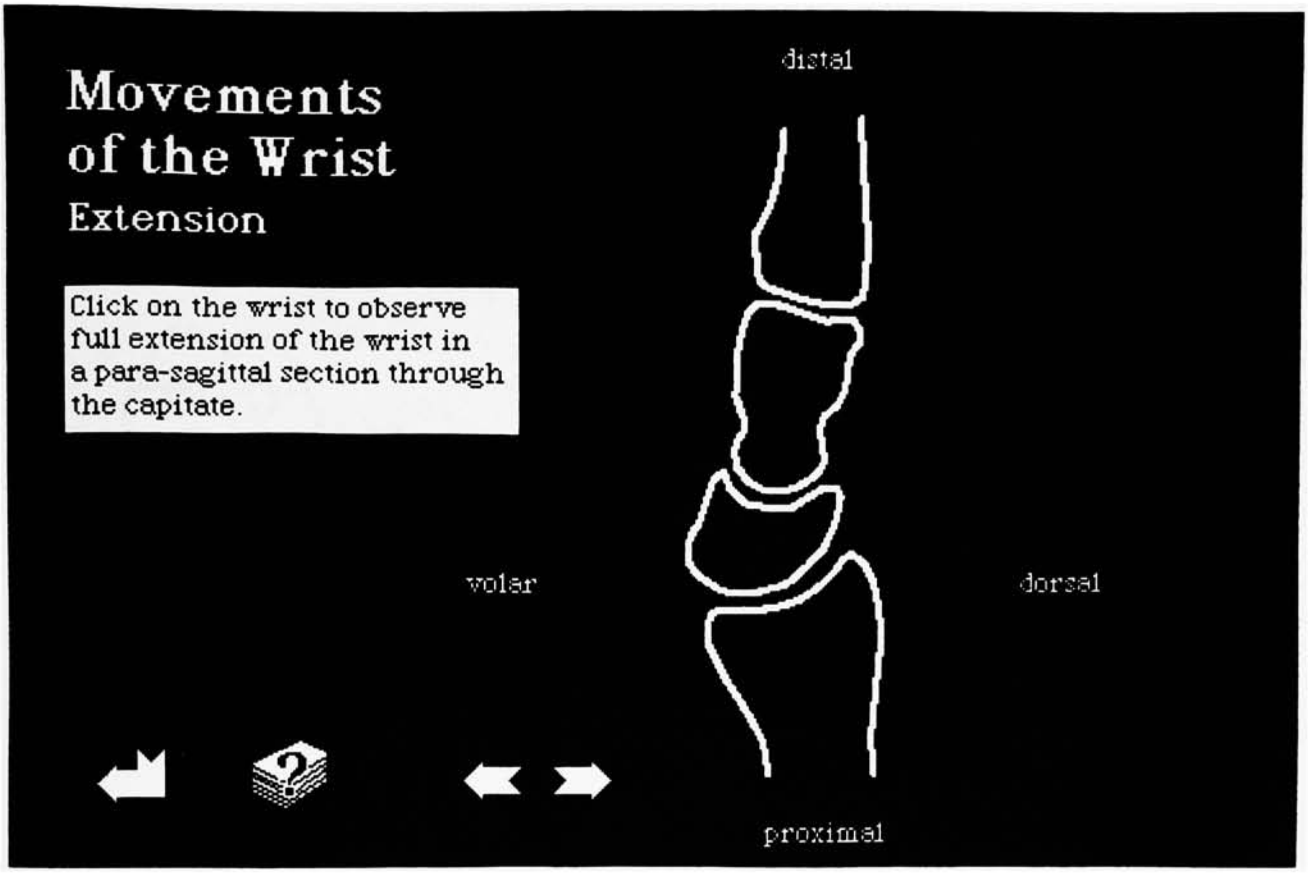
Para-sagittal section of the wrist

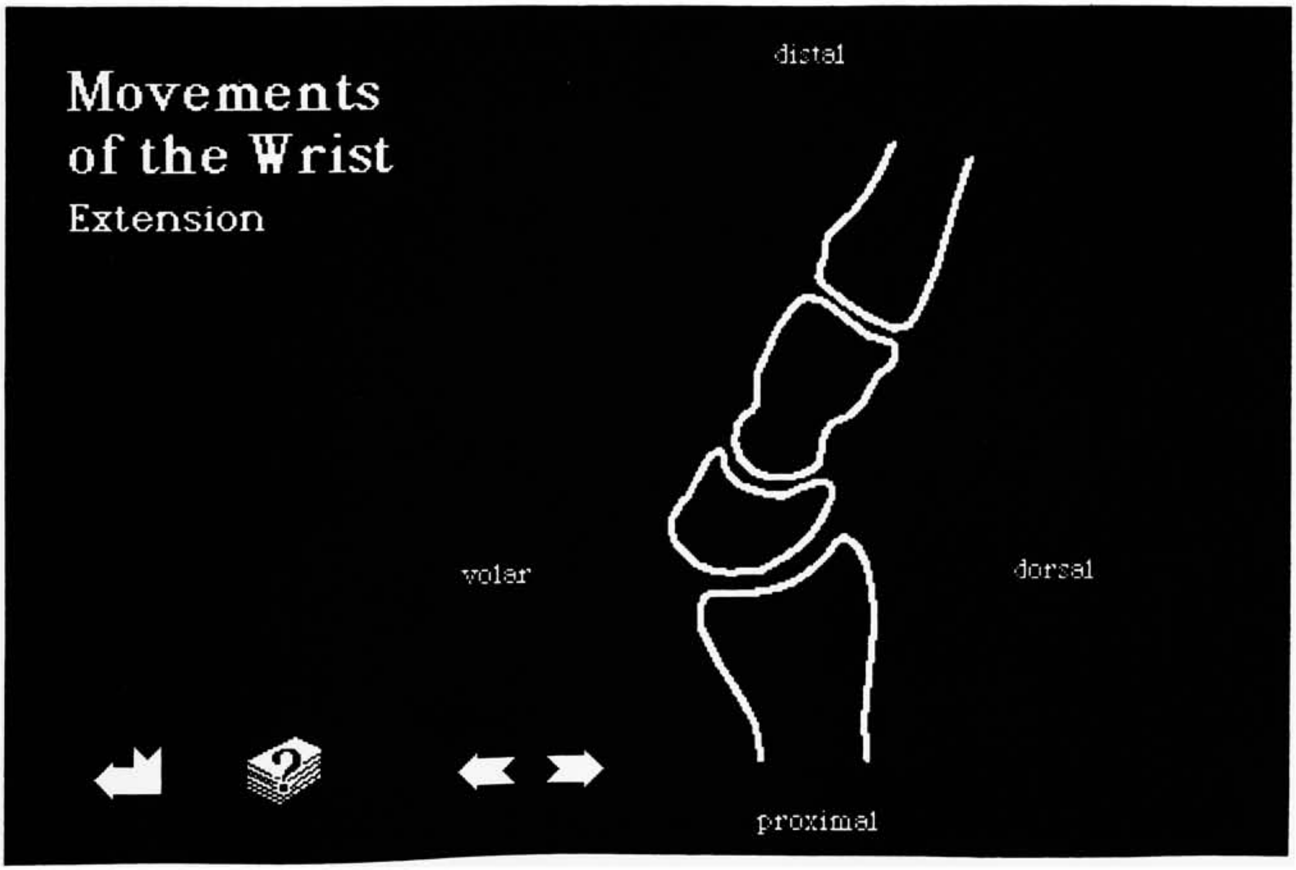


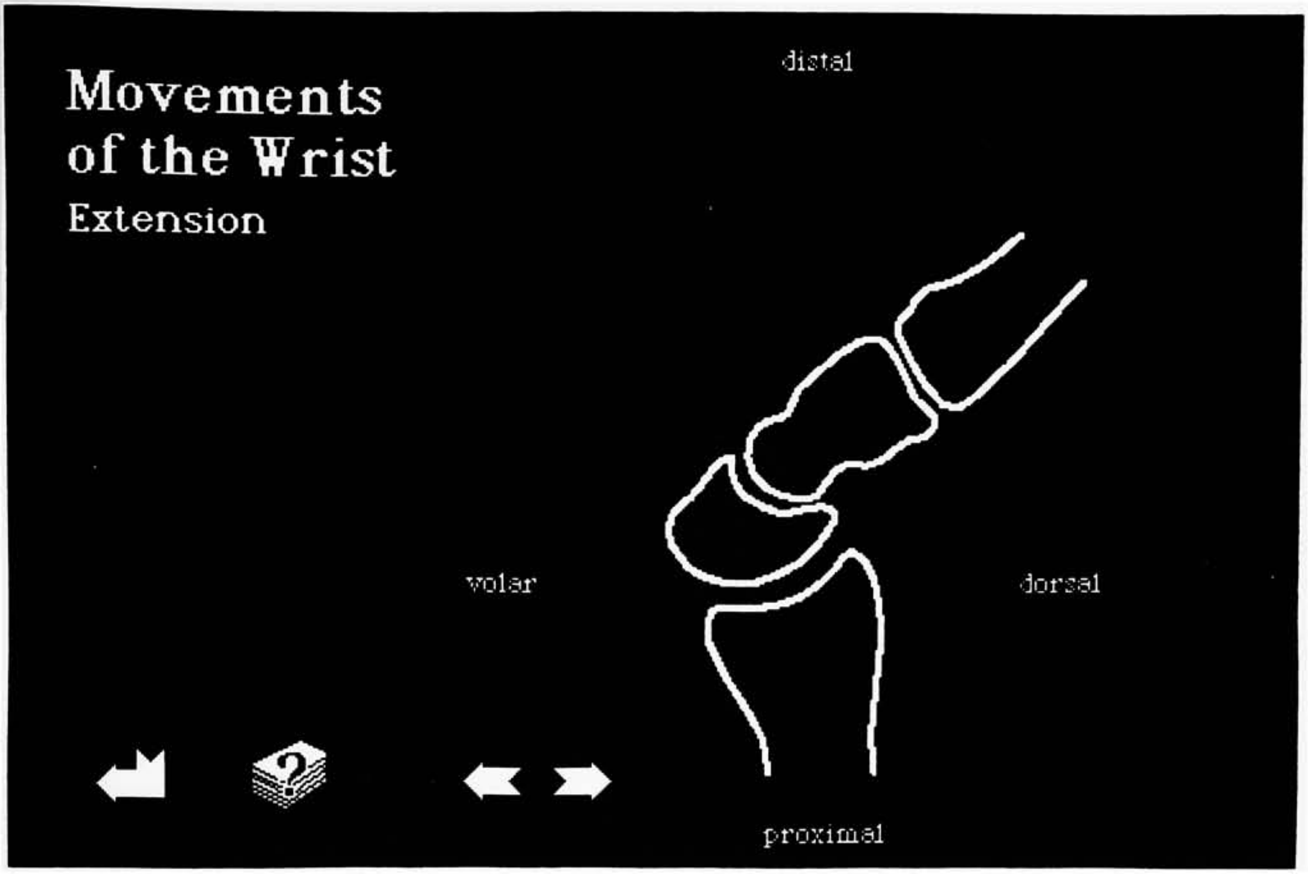
Movements of the Wrist

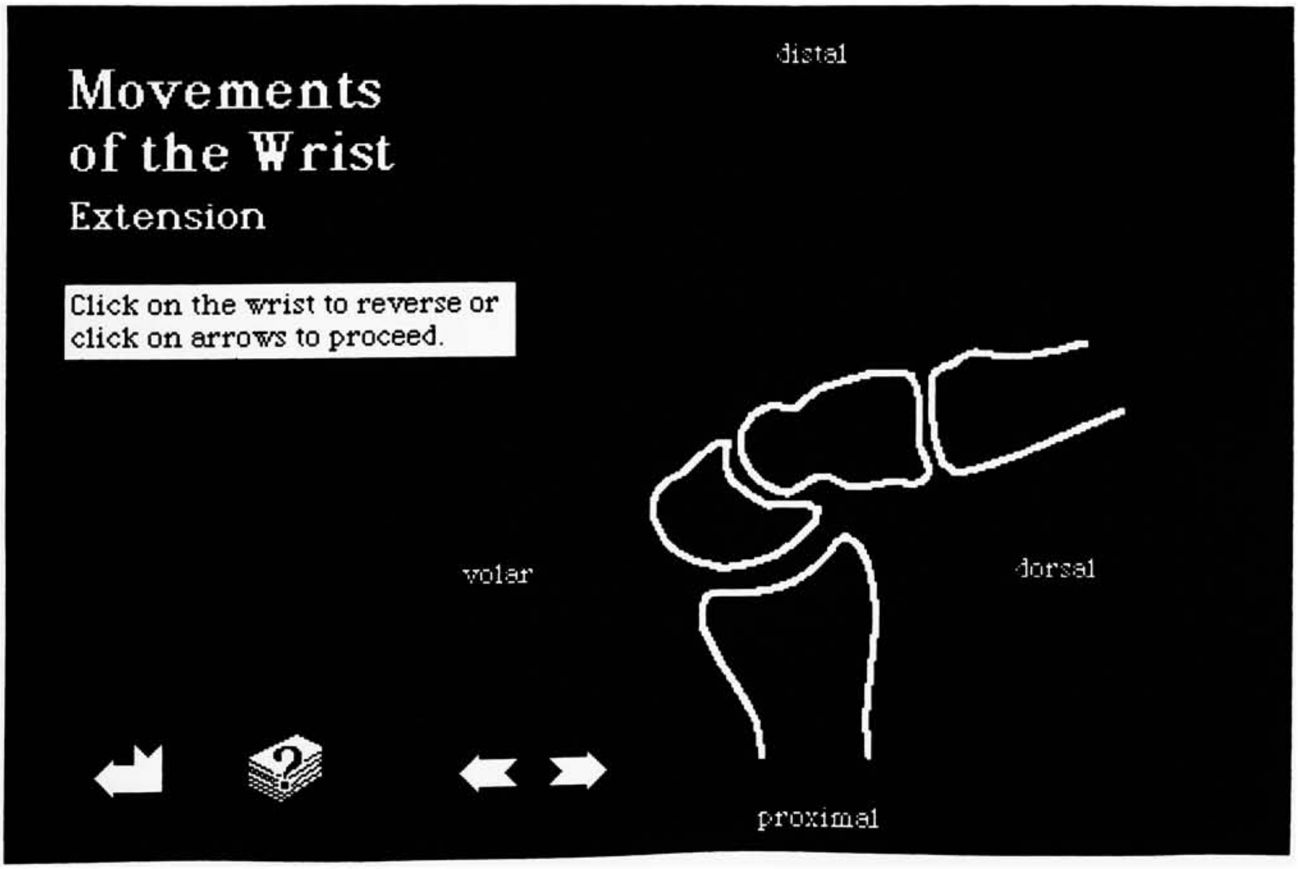
Extension

- In extension, the carpus rotates dorsally through an angle of approximately 70 °
- The axis of rotation lies in the frontal plane and passes through the head of the capitate
- There are actually two different motions involved: 1) The fixed unit rotates relative to the proximal row around the capitate-centered axis. 2) As the extensor muscles pull the carpus proximally, the proximal row bones are translated volarly along the volarly-sloping surface of the radius. This motion occurs along the circumference of a circle centered in the head of the capitate. The proximal row ends up translated volarly and in an extended position
- Each proximal row bone moves to a different degree. The scaphoid extends about 47 ° . The angle between the scaphoid an fixed unit, then, is about 23 ° during full extension. The triquetrum extends about 35 ° and the lunate about 30 ° , forming an angle with the fixed unit of 35 ° and 40 ° , respectively.


Movements
of the Wrist
Extension
Click on the wrist to observe full extension of the wrist in a para-sagittal section through the capitate.
distal
volar
dorsal
proximal


Movements
of the Wrist
Extension
distal
volar
dorsal
proximal


Movements
of the Wrist
Extension
distal
volar
dorsal
proximal


Movements
of the Wrist
Extension
Click on the wrist to reverse or
click on arrows to proceed.
distal
volar
dorsal
proximal

Movements of the Wrist

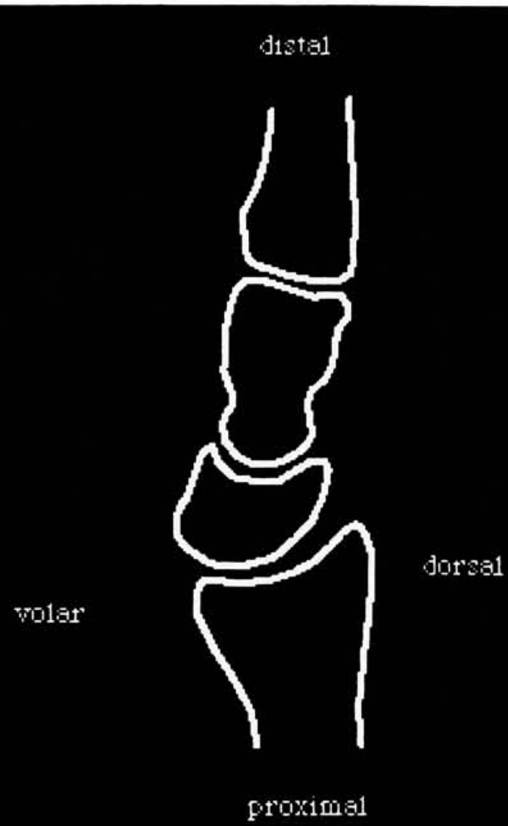
Flexion

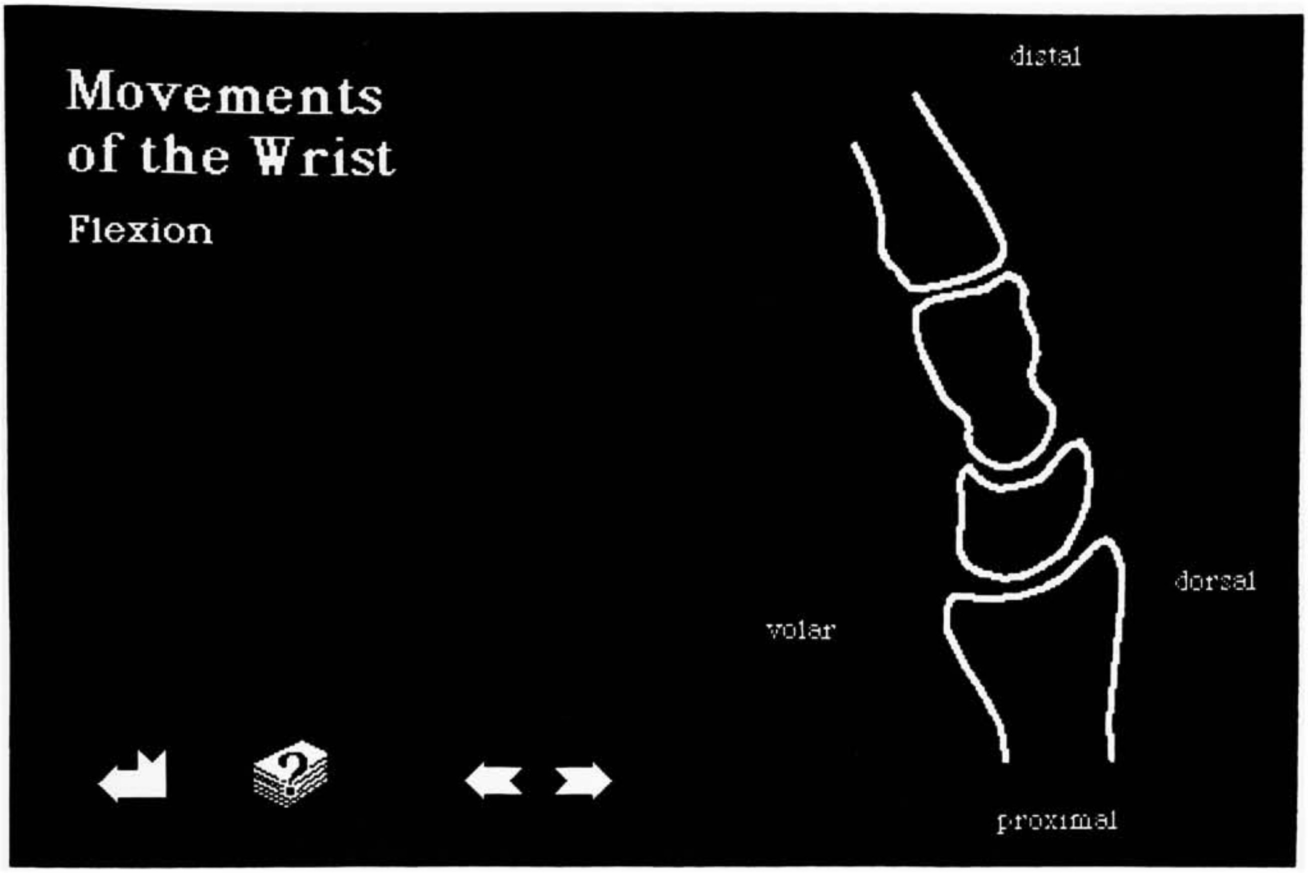
- The carpus rotates volarly through an angle of 90°.
- As in extension, there are tow components of this motion, both centered about an axis lying in the frontal plane and passing through the head of the capitate.
- The fixed unit rotates about this axis, flexing relative to the proximal row.
- As the fixed unit is pulled proximally by the flexor tnedons, it impinges on the distal pole of the scaphoid, causing the scaphoid and entire proximal row to flex.
- The scaphoid flexes approximately 60° . The triquetrum flexes approximately 45° and the lunate about 40°.
- In full flexion, the fixed unit forms an angle with the scaphoid of about 30°, with the triquetrum of about 45°, and with the lunate of about 50°.

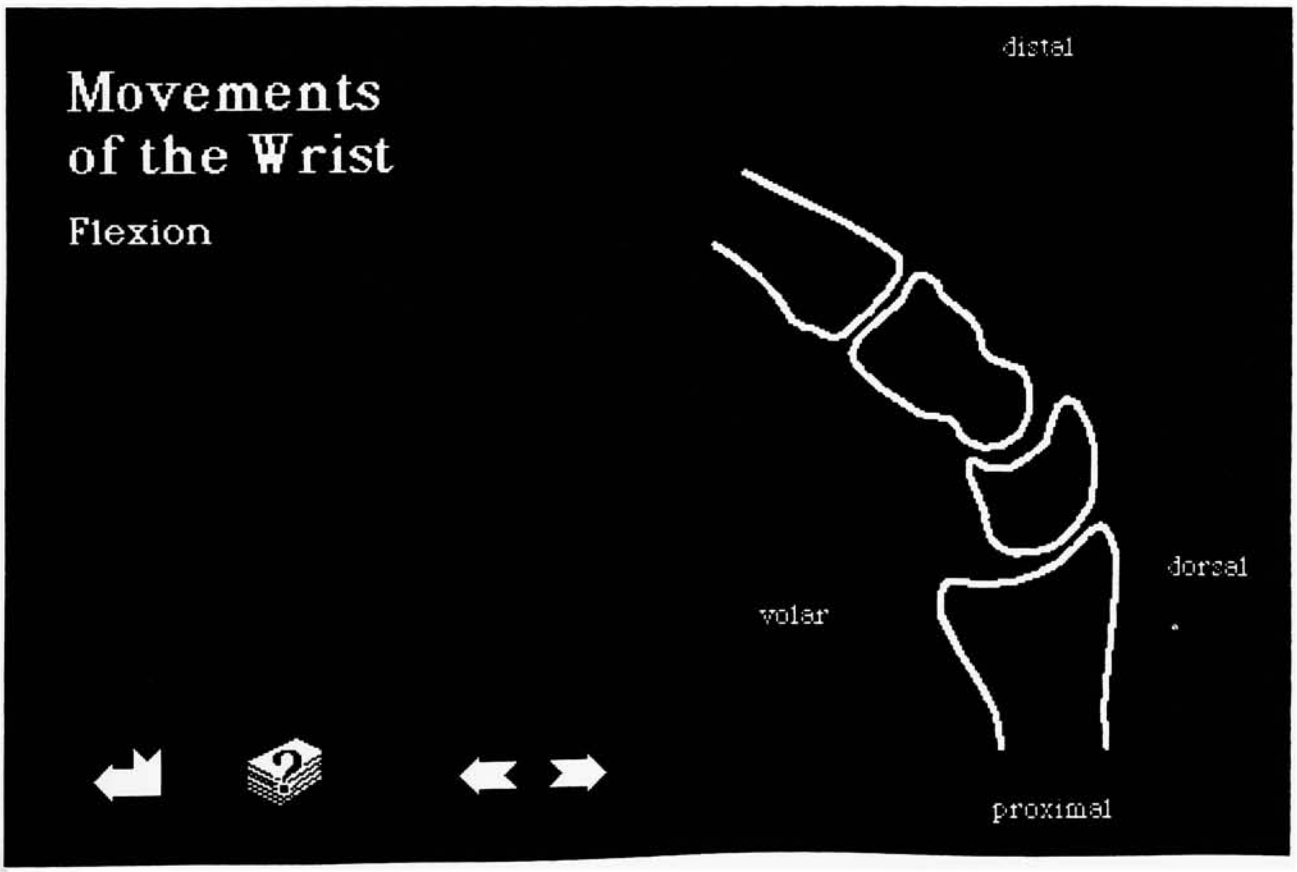
Movements of the Wrist

Flexion

Click on the wrist to observe full flexion of the wrist in a para-sagittal section through the capitate.



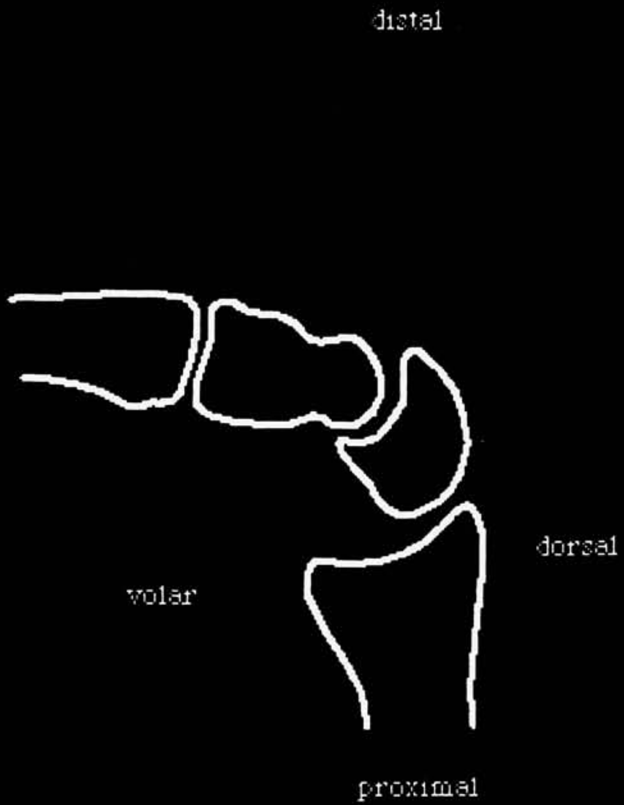

Movements
of the Wrist
Flexion
distal
dorsal
volar
proximal


Movements
of the Wrist
Flexion
distal
dorsal
volar
proximal

Movements of the Wrist

Flexion

Click on the wrist to reverse or click on arrows to proceed.



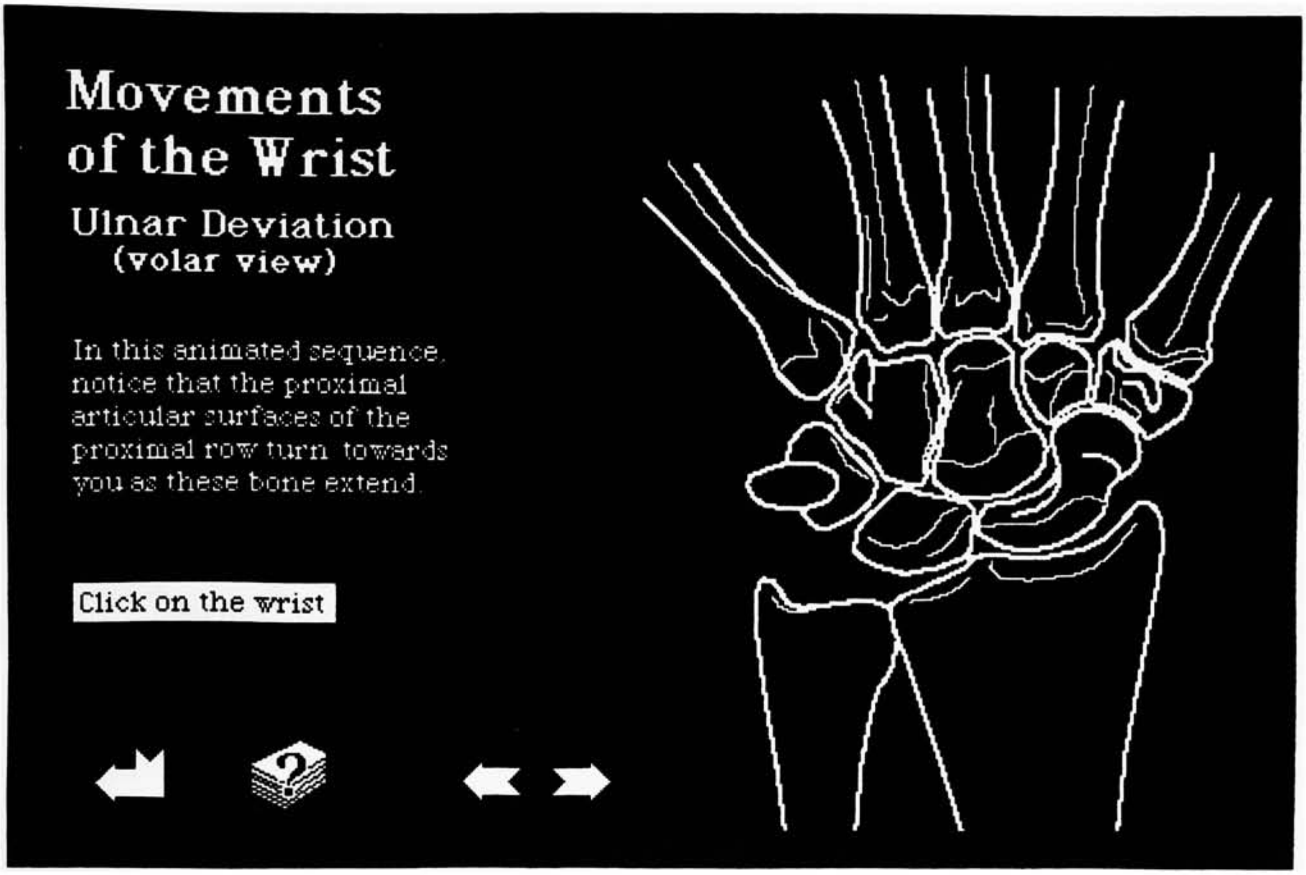
Movements of the Wrist

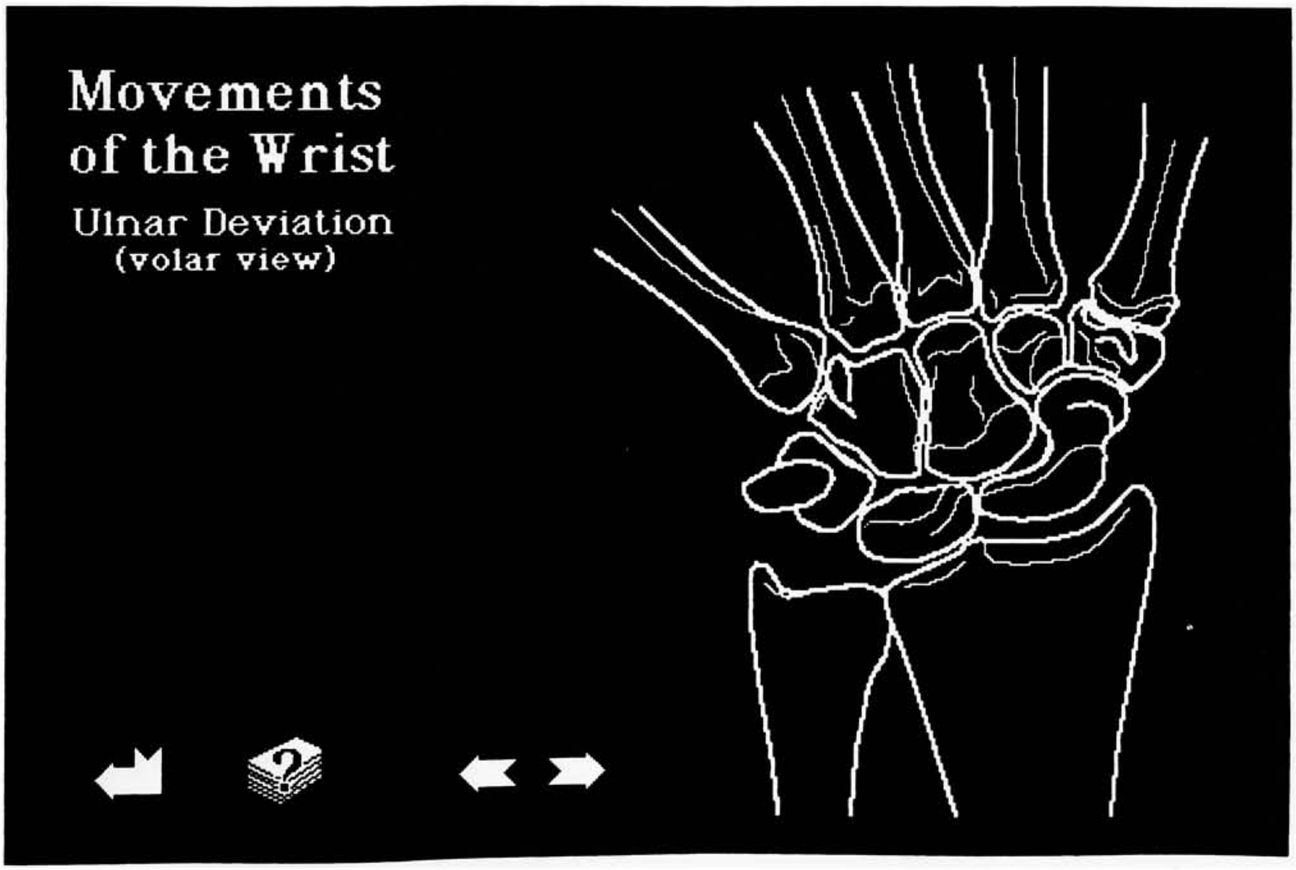
Ulnar Deviation

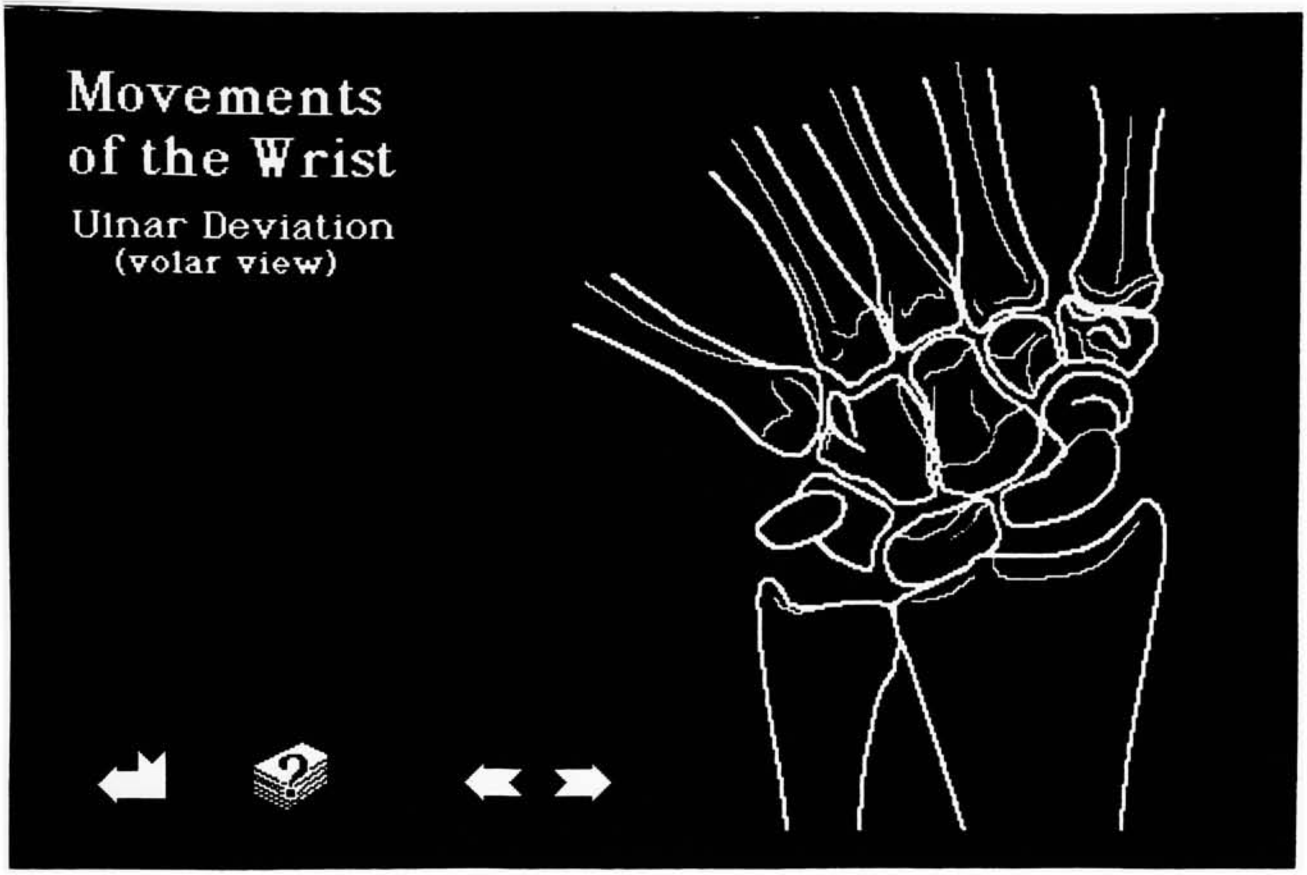
- The entire carpus rotates about an antero-posterior axis which passes through the head of the capitate

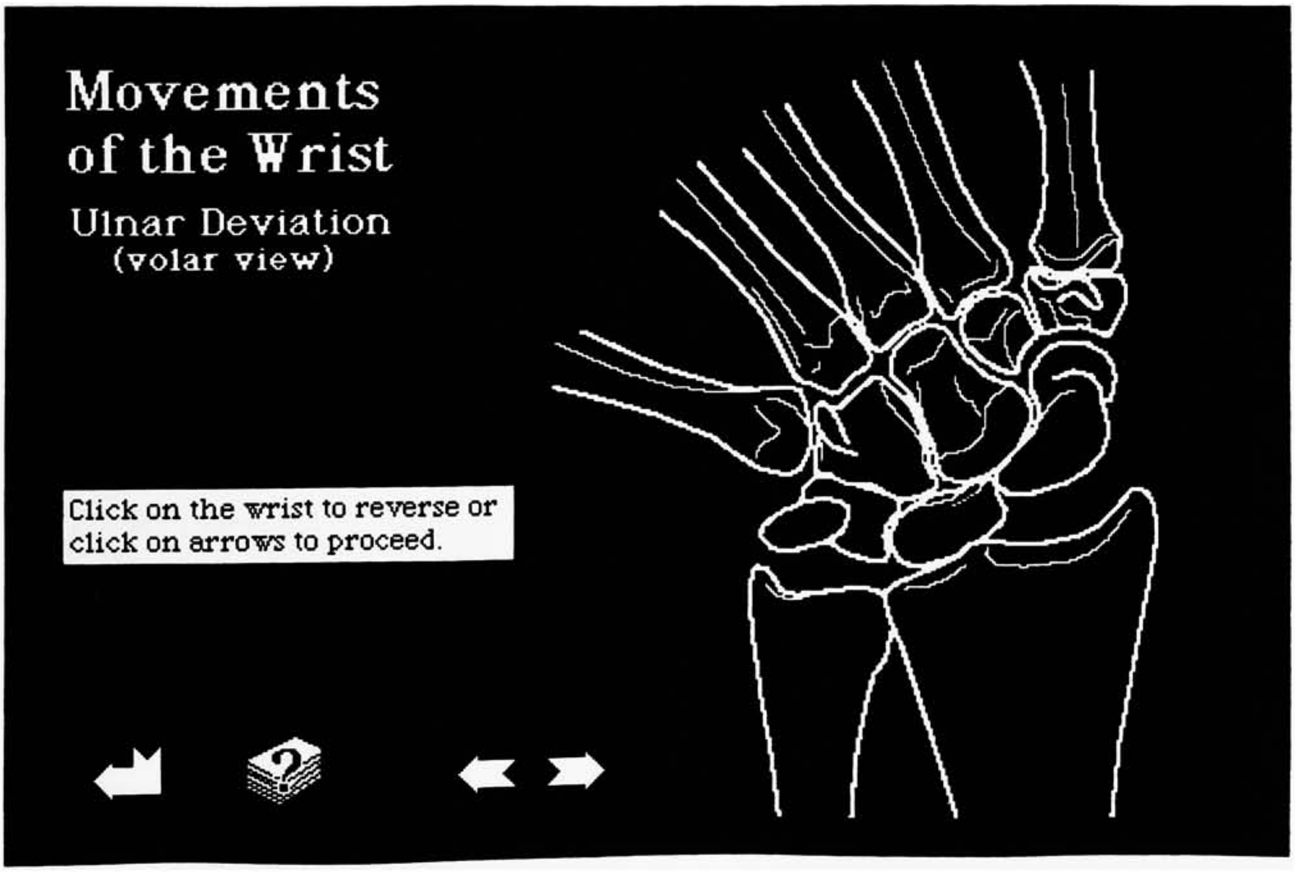
- The full range of motion from the neutral position is about 40°.

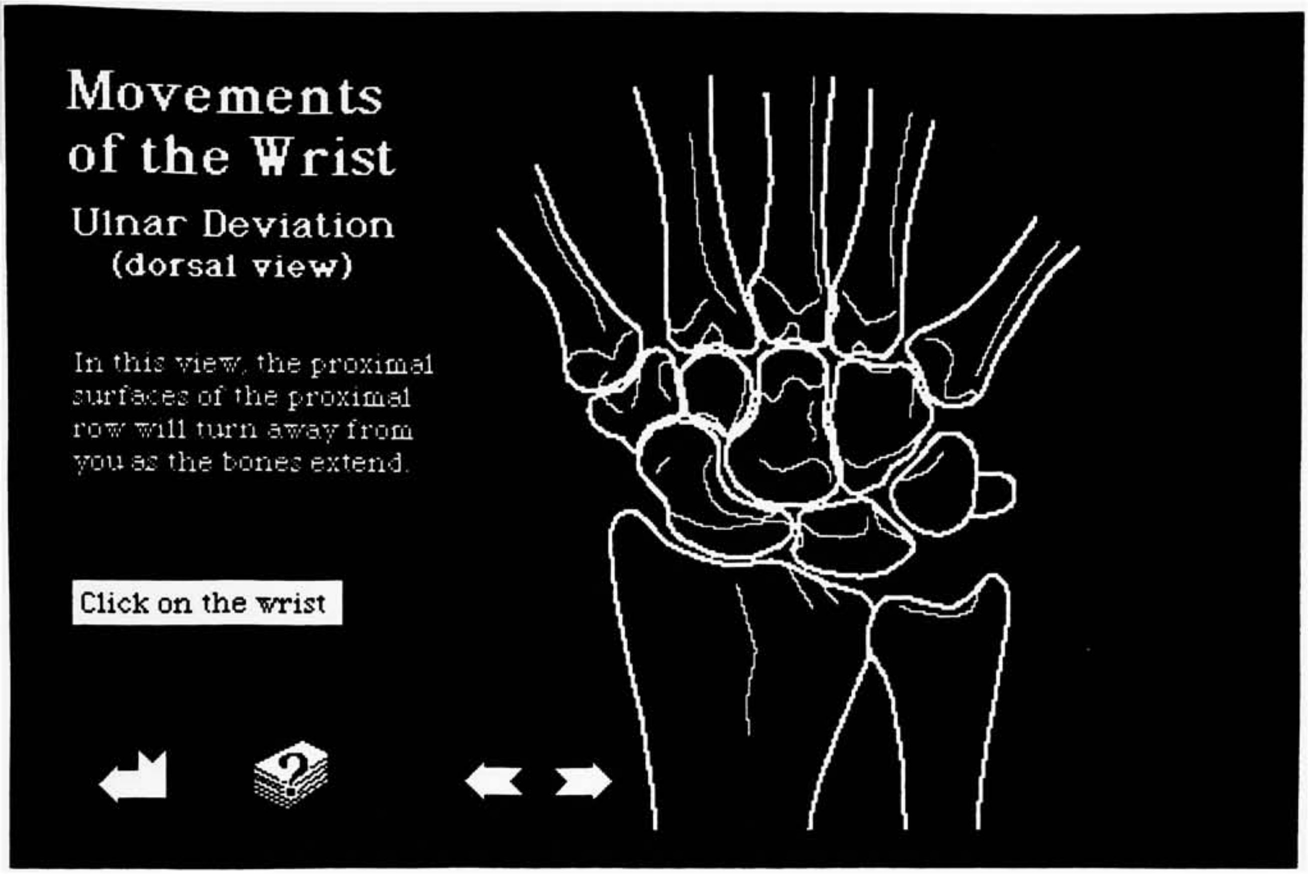
- As the carpus is pulled toward the radius, the proximal row bones are translated volarly and extend, just as they do in extension. The scaphoid extends the most, the lunate the least, and the triquetrum is intermediate.

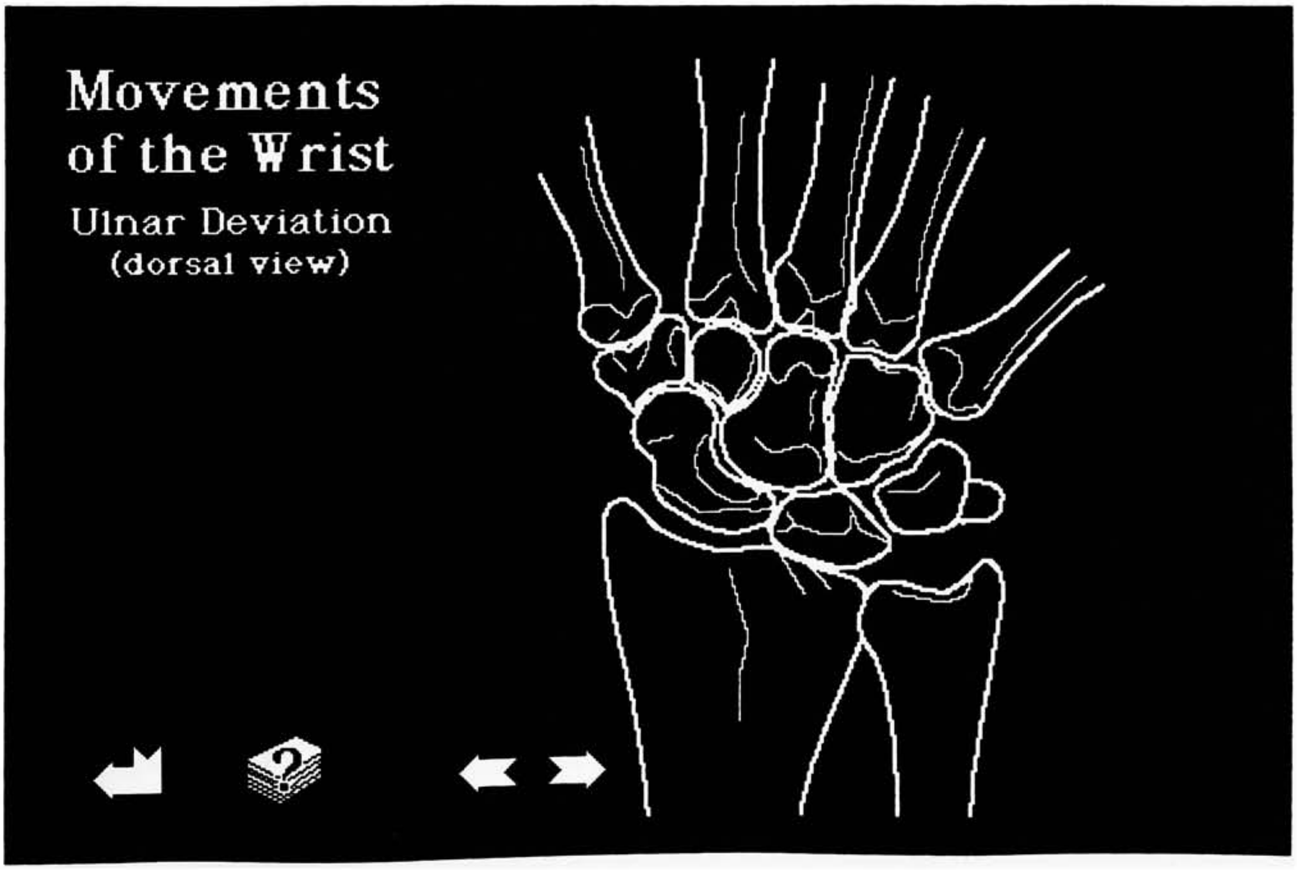

Movements
of the Wrist
Ulnar Deviation
(volar view)
In this animated sequence, notice that the proximal articular surfaces of the proximal row turn towards you as these bone extend.
Click on the wrist

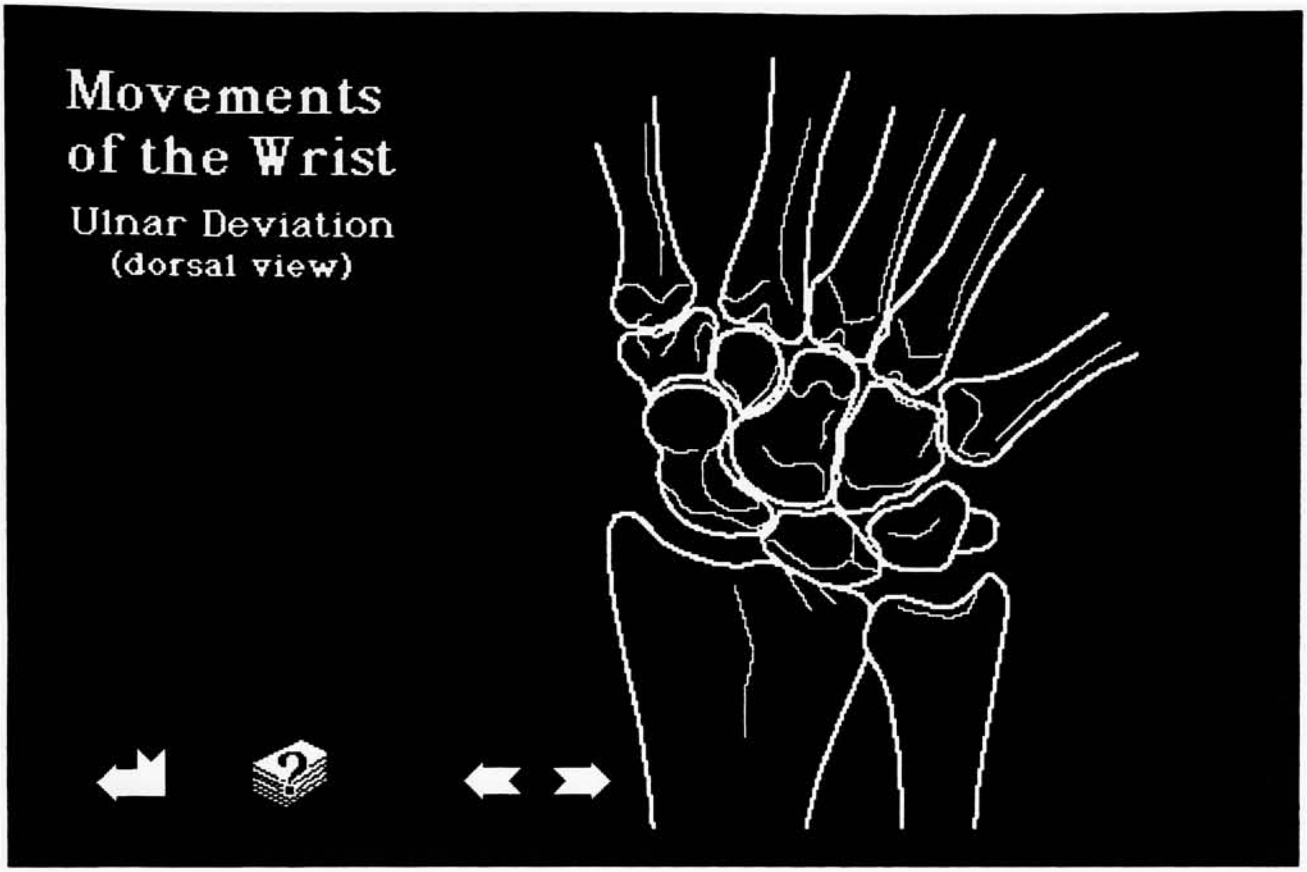

Movements
of the Wrist
Ulnar Deviation
(volar view)

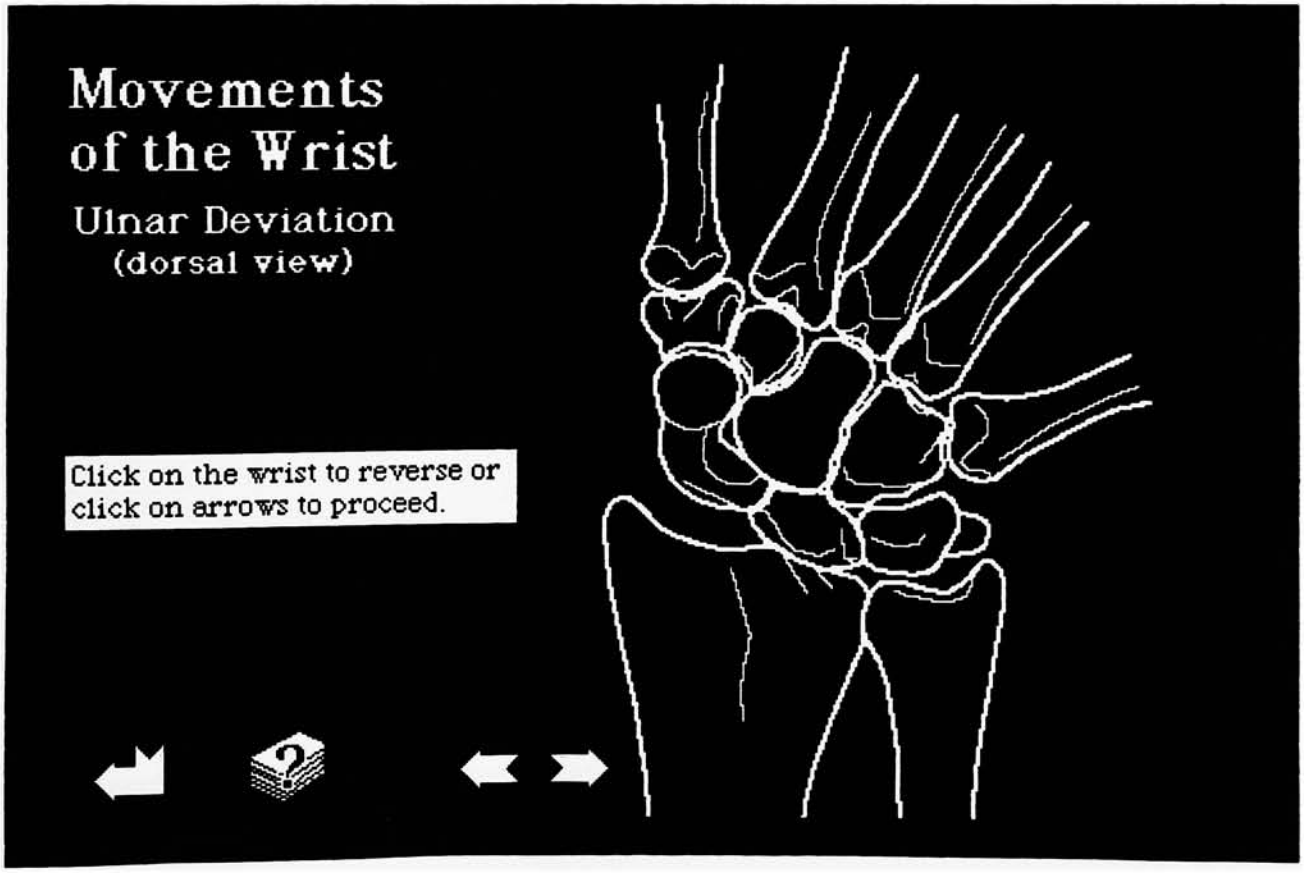

Movements
of the Wrist
Ulnar Deviation
(volar view)


Movements
of the Wrist
Ulnar Deviation
(volar view)
Click on the wrist to reverse or
click on arrows to proceed.


Movements
of the Wrist
Ulnar Deviation
(dorsal view)
In this view, the proximal surfaces of the proximal row will turn away from you as the bones extend.
Click on the wrist


Movements
of the Wrist
Ulnar Deviation
(dorsal view)


Movements
of the Wrist
Ulnar Deviation
(dorsal view)


Movements
of the Wrist
Ulnar Deviation
(dorsal view)
Click on the wrist to reverse or
click on arrows to proceed.

Movements of the Wrist

Radial Deviation

- The entire carpus rotates about an antero-posterior axis which passes through the head of the capitate.

- The full range of motion from the neutral position is about 10°.

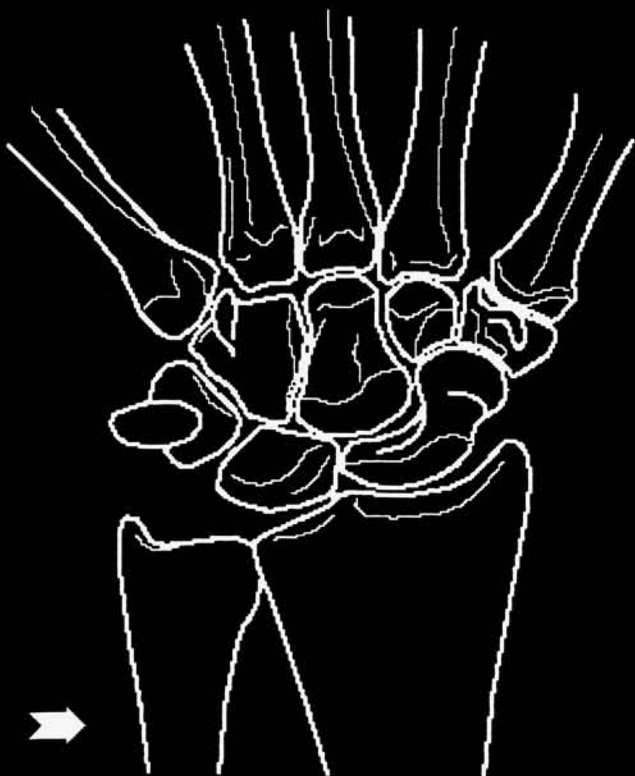
- As the carpus is pulled toward the ulna, the fixed unit impinges on the distal pole of the scaphoid causing it and the other proximal row bones to flex. The scaphoid flexes the most, the lunate the least, and the triquetrum is intermediate.

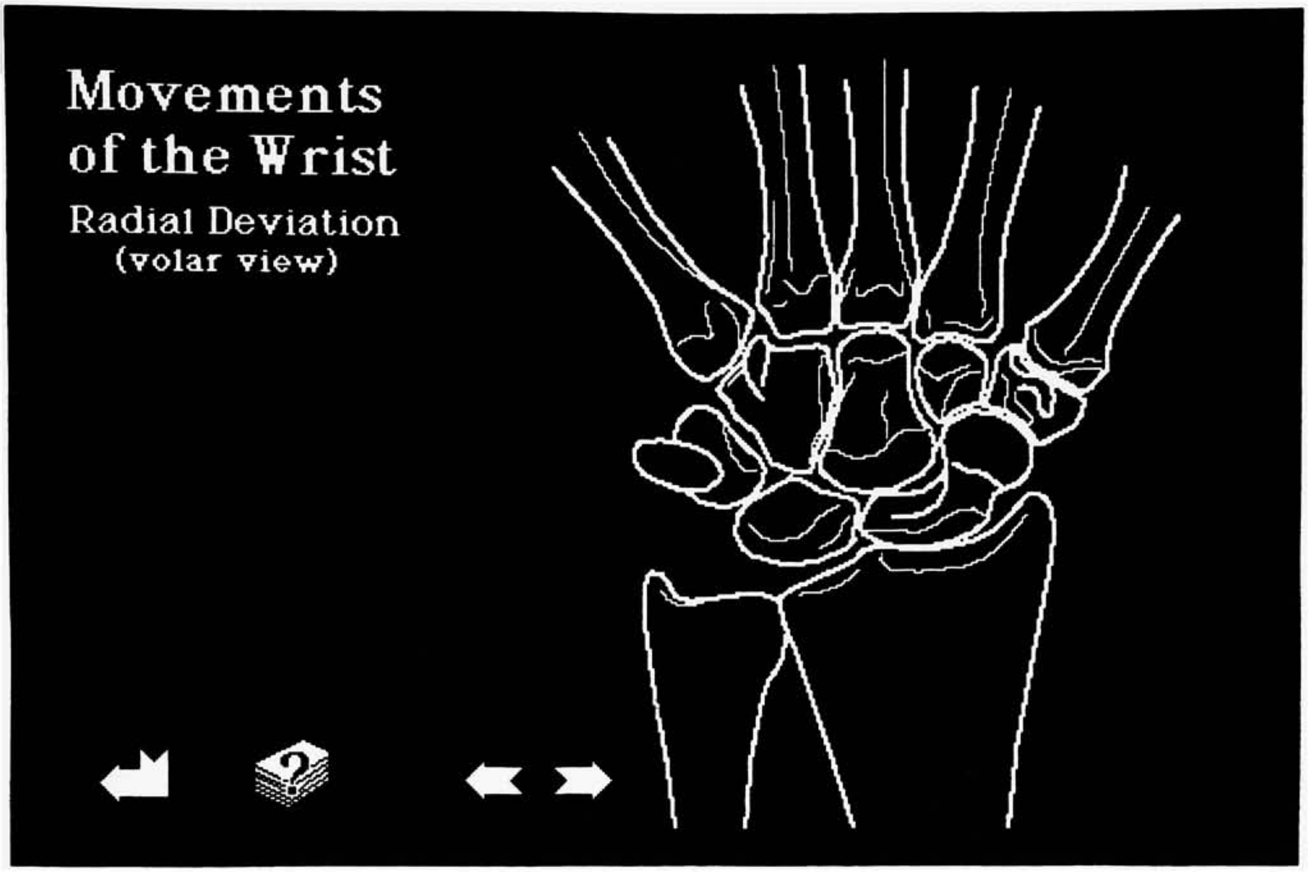
Movements of the Wrist

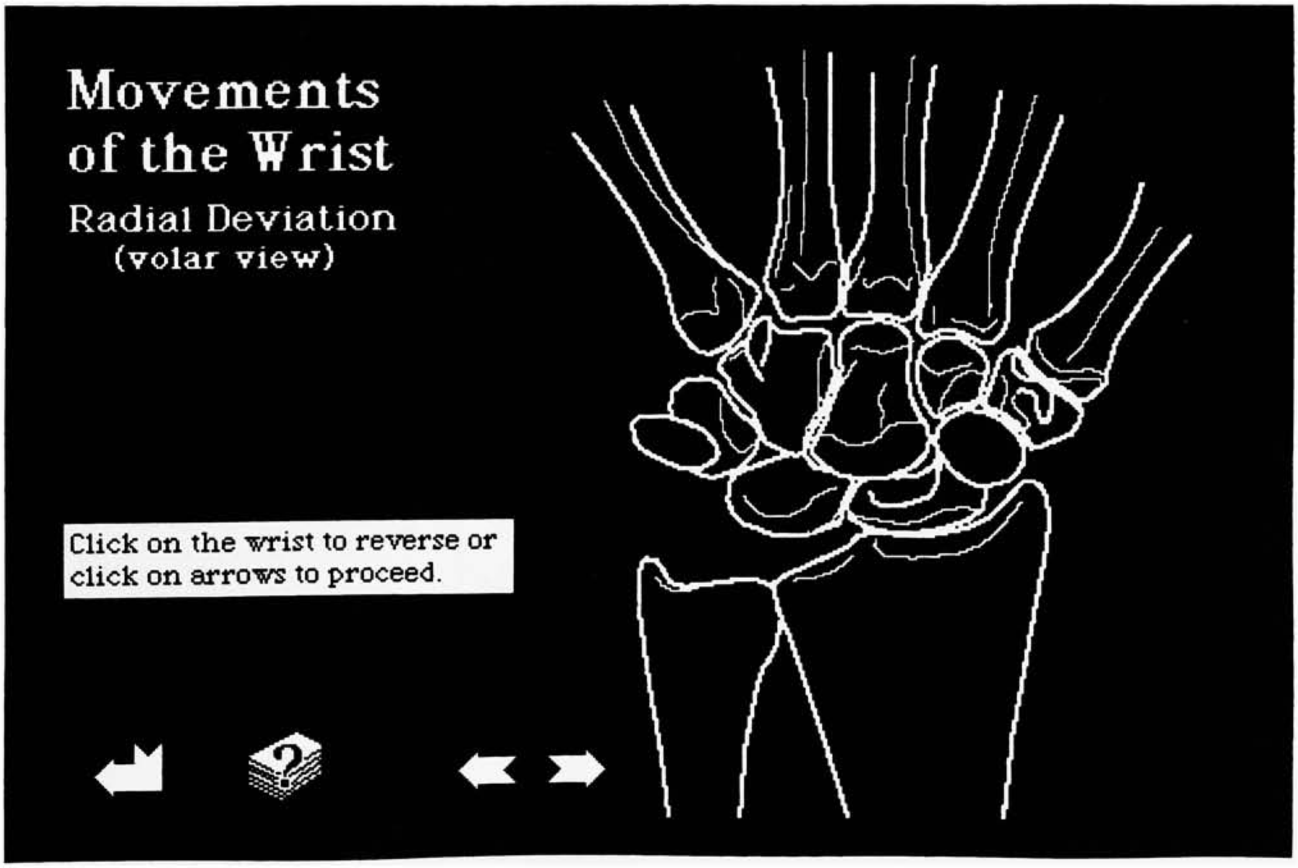
Radial Deviation
(volar view)

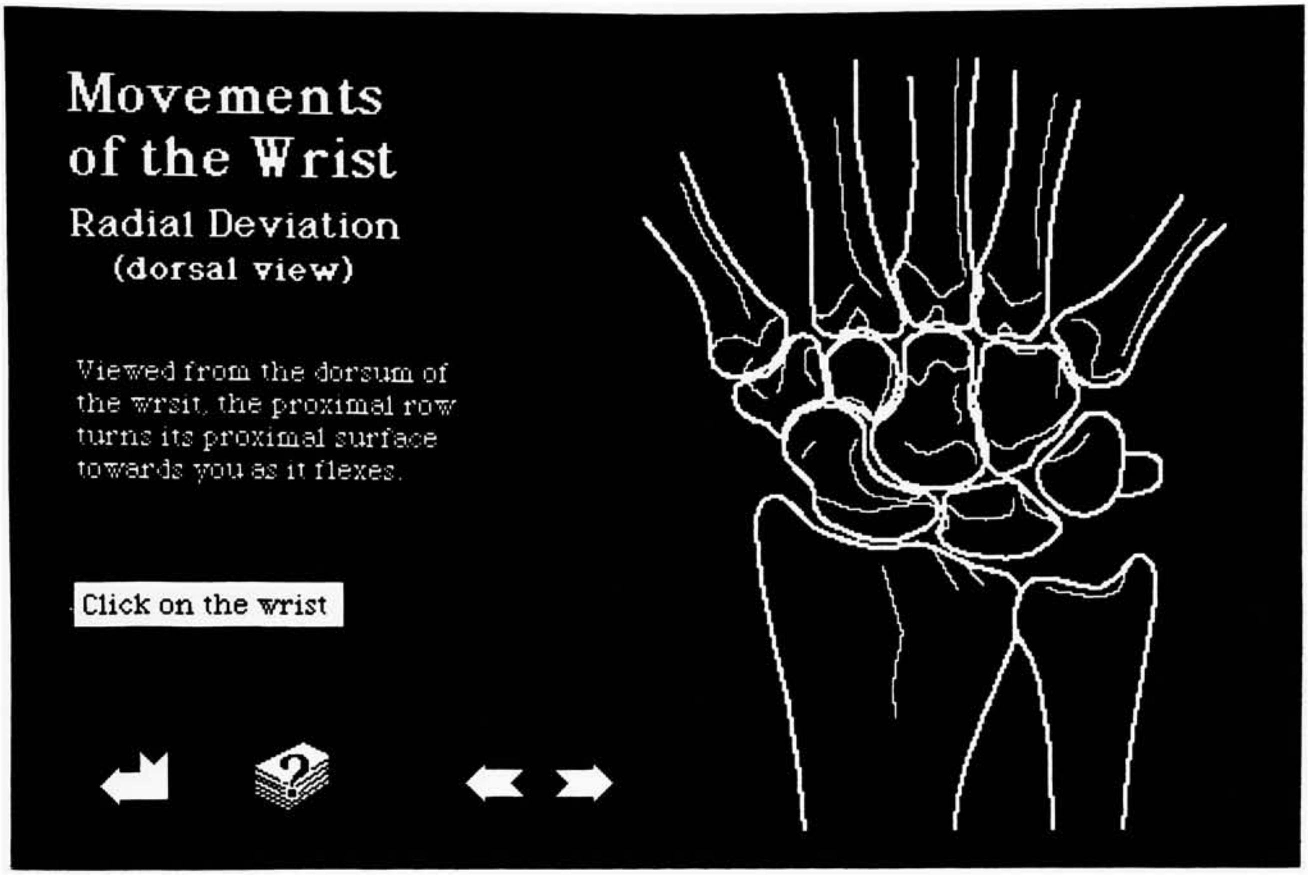
In this sequence, the proximal row flexes, turning its proximal articular surface away from you.

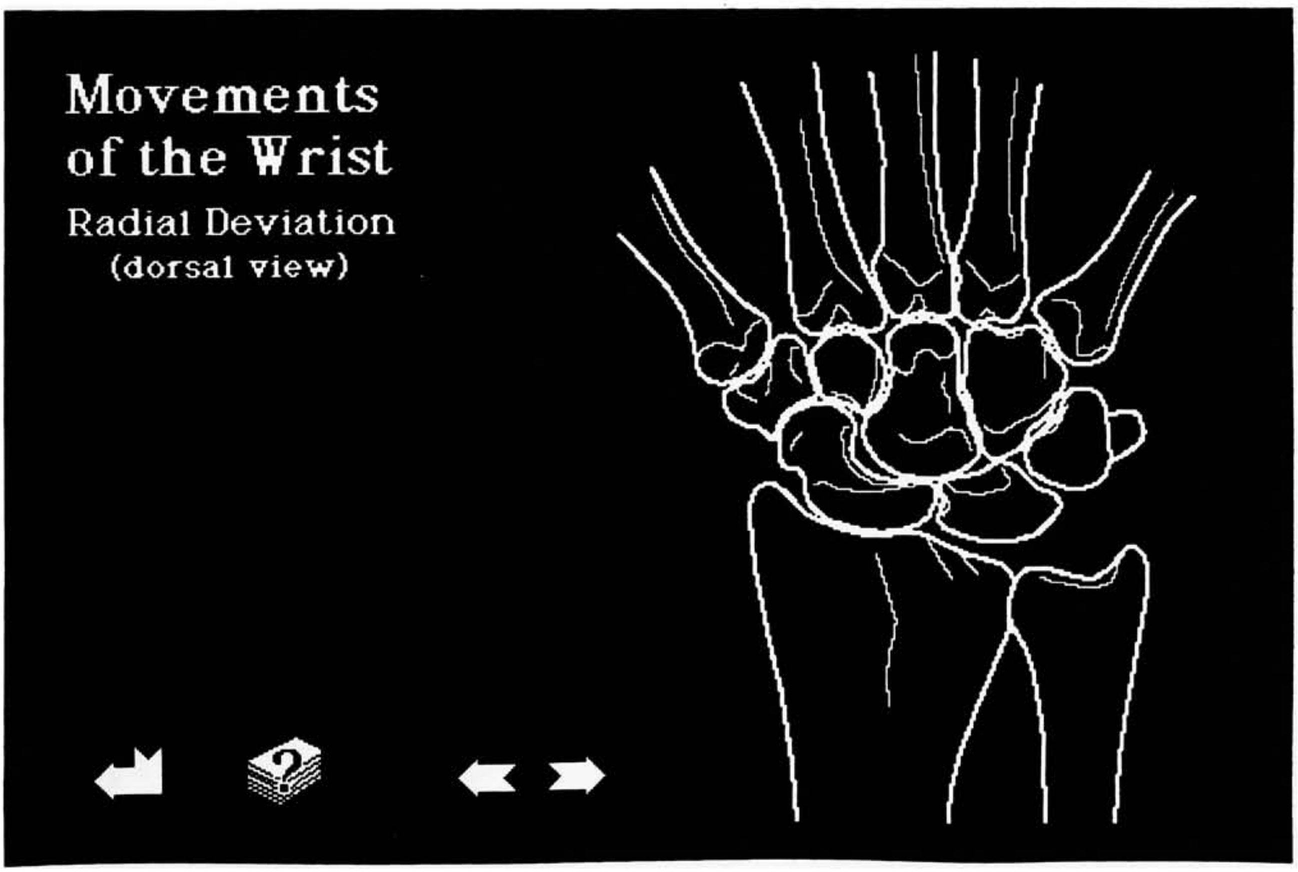
Click on the wrist




Movements
of the Wrist
Radial Deviation
(volar view)


Movements
of the Wrist
Radial Deviation
(volar view)
Click on the wrist to reverse or
click on arrows to proceed.

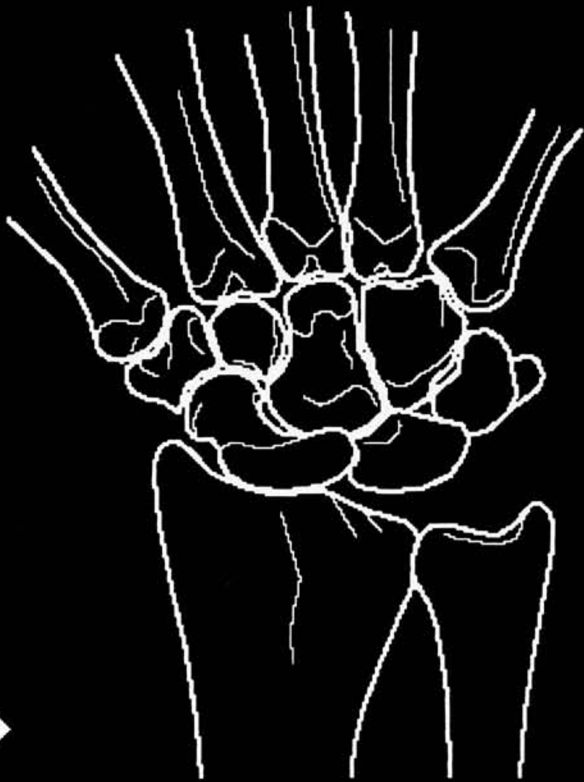

Movements of the Wrist
Radial Deviation
(dorsal view)
Viewed from the dorsum of the wrsit, the proximal row turns its proximal surface towards you as it flexes.
Click on the wrist


Movements of the Wrist
Radial Deviation
(dorsal view)

Movements of the Wrist

Radial Deviation

(dorsal view)



Click on the wrist to reverse or click on arrows to proceed.

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